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3-VDA
Institution

MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

VOL. CXXI.

EDITED BY

JAMES FORREST, ASSOC. INST. C.E., SECRETARY.

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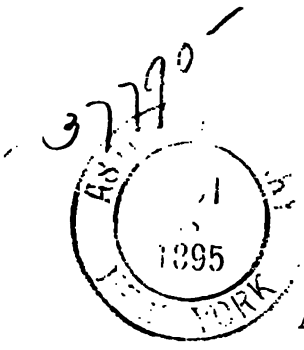

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CORRIGENDA.

Vol. cxix. p. 223, line 6 of Table, *for* "0·33500" *read* "0·03350."
Vol. cxx. p. 181, *Figs. 17, 18* and *19* should be inverted.
,, p. 185, Footnotes 1 and 2 should be transposed.
,, p. 431, line 15 from bottom, *for* "Saaran" *read* "Saarau."
,, p. 432, line 20 from bottom, *for* "alcined" *read* "calcined."
,, p. 436, line 2, *for* "line" *read* "lime"; *for* "changing" *read* "charging."
,, p. 436, line 23, *for* "or regular" *read* "or in regular."

THE

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1894-95.—PART III.

SECT. I.—MINUTES OF PROCEEDINGS.

19 February, 1895.

SIR DOUGLAS FOX, Vice-President,
in the Chair.

(*Paper No. 2866.*)

"Plant for the Extraction of Gold by the Cyanide Process."

By CHARLES BUTTERS and EDGAR SMART, Assoc. M. Inst. C.E.

THE process of extracting gold from ores and tailings by solutions of cyanide of potassium, now so largely used on the Witwatersrand gold-fields, need be here but briefly described, as the object of this Paper is to deal with the process in its mechanical rather than in its chemical aspects.

The treatment is chiefly applied to tailings, that is to say, to crushed ore that has already been passed over the ordinary amalgamating tables. These tailings are placed in suitable vats, and are subjected to the action of solutions of cyanide of potassium of strengths varying between 40 lbs. and 2 lbs. of cyanide to 1,000 gallons of water, or between 0·4 per cent. and 0·02 per cent. These dissolve the gold, and are leached from the tailings and passed through boxes in which the gold is precipitated, either by means of zinc shavings or by electricity. The solutions are made up to their former strengths and applied again to fresh tailings. When these are old and contain a quantity of partially decomposed pyrites, their acidity requires to be neutralized by an alkaline wash, caustic lime and caustic soda being usually employed; so that in many cases provision has to be made in the works for circulating and storing three separate solutions, viz., strong cyanide, weak cyanide, and the alkaline wash, as well as for the water-supply sometimes required for preliminary or final washing.

DESIGN OF CYANIDE WORKS.

Site.—The ideal site for works of this class is one having a fairly steep and uniform slope downwards from the material to be

treated. This not only allows the top of the treatment-vats to be placed below the level of the tailings, which may be therefore run into the vats by gravity, but also affords plenty of space below the works for dumping the residues after treatment. Unfortunately many of the early batteries on the Rand gold-fields were placed at a low level near water, instead of high up near the shafts, apparently because it was considered easier to transport a small quantity of rock than to pump the necessary quantity of water. In such a case either the tailings or the residues or both must be hauled up, and it is usual to place the works high enough to provide for four or five years' dumping-ground, and to haul the tailings to the top of the vat, so as to do all the lifting at one operation, and to keep the works as far as possible free from irritating sand in windy weather. The plan and sections of the Main Reef works, Figs. 1, Plate 1, show a very convenient site, and those of the Simmer and Jack works, Figs. 3, a very inconvenient one, as there is little fall in any direction, while the tailings to be treated are distributed over a large area of ground.

Vats.—The size and number of the vats depend not only on the actual quantity of material to be treated, but also on the time occupied in filling and discharging as well as of leaching, which varies with the nature of the material, and with the consequent number and amount of the solutions applied. The time allowed for the zinc process is generally between sixty and eighty-four hours, vats of 300 tons or 400 tons capacity being usually discharged and filled in one working day, of ten to twelve hours, giving ninety-six hours as the total required per vat with the zinc process. That is to say, a complete cycle of operations occupies just four days and nights, so that if one tank per day is to be treated, four vats must be provided. Where the material is so far amenable to treatment that sixty hours' leaching is sufficient, it is evident that three vats will be the minimum number. With the appliances generally in use on the Rand gold-fields, it may be said that for treating more than 400 tons per day it is better to provide five tanks, so that one can be discharged and another filled simultaneously, the result being equivalent to four vats in the former case. In the Siemens-Halske electrical process, the minimum time occupied is one hundred and ten hours, on account of the extremely dilute solutions which can be used, thereby effecting a considerable economy in cyanide. To permit of one vat being filled and emptied each day five vats must be provided, and where two days are occupied in charging and discharging, six vats should be built. Except in cases where special facilities

for filling and discharging exist, the Authors would not recommend a larger capacity for the vats than, say, 600 tons, but up to that limit it has been ascertained in practice that a few large vats are much more convenient than a large number of small ones.

Solution-Tanks and Zinc-Boxes.—It is found that a tankful of tailings, containing between 10 per cent. and 15 per cent. of moisture, requires about one-third of its volume of water to fill it, and solution-tanks of between one-third and two-thirds the capacity of each leaching-vat have been used, but they have usually been all of the same size at each works. There is, however, room for improvement in this respect. The amount of weak solution in use is generally largely in excess of the strong solution or alkaline wash, and by a test-treatment of the tailings in each case, the size of the tanks for each solution can be approximately determined. For ordinary clean tailings of moderate acidity, and a plant with five vats, each of 600 tons capacity,—suitable sizes, giving ample margin for the alkaline-wash, strong-solution and weak-solution tanks, are of 300 tons, 300 tons and 450 tons capacity respectively. For convenience 26 cubic feet of water is reckoned to the ton.

In determining the sizes of zinc-boxes the following figures will be of use in conjunction with the details of the works to be described. The total amount of solution to be precipitated per ton of sand varies between $\frac{3}{4}$ ton in large works treating 600 tons per day, and 1 ton in small works treating 100 tons per day. Effective precipitation is obtained with an average rate of flow of about 26 feet per hour through boxes of between 18 feet and 24 feet long, 2 feet 3 inches deep, and 3 feet wide. The capacity of the boxes may be determined according to the following rule which has given good results: for each ton (26 cubic feet) of solution to be precipitated per hour, 21 cubic feet are to be allowed in the zinc-box.

Filling and Discharging.—In the earliest cyanide works erected on the Rand gold-fields, square wooden tanks, about 3 feet 6 inches deep and arranged in parallel rows, were employed. These were filled by side-tipping trucks from gangways carried over the top of the tanks. On each side of the tanks between the rows other rails were laid on the ground, level with the tank bottom for the discharging trucks, into which the sand was shovelled over the sides of the tanks. The introduction of the Butters bottom-discharge at the Robinson Gold Mining Company's chlorination and cyanide works, designed by the Authors, was the first improvement on this method. The cyanide works have twelve cylindrical wooden leaching-vats, 20 feet in diameter, and with 8-foot staves, which were

erected on circular stone piers, with a tunnel through the middle of each pier, giving sufficient headroom for men and mules. In the centre of each vat-bottom a door is fixed, through which all the tailings can be shovelled downwards into trucks in the tunnel. By this method each native labourer can discharge about 30 tons in ten hours as against 10 tons by the former method. The filling-trucks travel on gangways carried on the posts of the main shed clear of the vats. Side-discharges have also been used in wooden vats, but at a distinct disadvantage compared with the bottom-discharge, except in the cases of very small vats, when there is little difference. But with a large vat many doors can be placed in the bottom, so spaced, by dividing the bottom into equal areas, as to obviate the shovelling across the tank towards the end of the discharge, which is an objectionable feature of the side-discharge in tanks of over 24 feet diameter.

In the new cyanide works of the Crown Reef and several other companies designed by Mr. Hennen Jennings, where square brick tanks have been erected, there are side-discharge openings extending the full height of the tanks and wide enough for a truck to enter. These are opened and closed by cast-iron doors suspended from bearers arranged on wheels, and can be readily shifted. In order to empty the vat the sand is gradually cut into, and after a time sufficient space is made to allow several trucks to be filled simultaneously.

At the Langlaagte Estate Company's works the leaching-tanks were excavated in good solid ground, and were lined with brick coated with cement. They are each 40 feet in diameter and 10 feet deep, and are placed in one row, their tops being level with the ground. The filling is effected by tipping from a platform elevated about 10 feet above the ground, the object of the elevation being to distribute the tailings over a large surface and thereby to reduce the labour of dressing to a minimum. An ordinary Priestman grab-dredger was first employed to raise the residues, but afterwards the use of the grab was abandoned and the steam-crane used alone, the bodies of the trucks being lifted from their carriages and lowered into the tank, where they were filled by shovelling, and then lifted again on to their carriages.

Transport of Tailings.—About four years ago a cyanide works with a capacity of 2,000 tons monthly was actually being charged by means of trains of trucks drawn by oxen. These have now given place to mules, hauling-engines, and various mechanical rope-haulage systems. Where the tailings are scattered or collected in shallow pits of large area, the use of stationary hauling-engines is

preferable on account of the great flexibility of the system, and its consequent adaptability to cases in which there are several loading-points and constantly shifting loading-lines. It is then probably the most economical for filling, especially when the material has to be hauled up an incline or where the pull is short. It is only where distances are great and the quantities large, or where the pulling is all from one fixed point to another, that mechanical haulage-systems effect economy, but when these conditions do occur they are certainly unrivalled for great capacity. For delivery from the settling-vats to the leaching-vats when these are not far apart, endless belts would in all probability be most suitable, but owing chiefly to the difficulty of obtaining such apparatus adapted to special cases at short notice, they have not hitherto been introduced.

Pumps and Pipes.—Manchester donkey-pumps and other steam- and centrifugal-pumps have been used, but in every case it is absolutely necessary that all parts in contact with the liquor should be of iron or steel and not of brass or gun-metal, as these latter are quickly attacked and corroded by the solution. The Manchester and Cameron pumps have worked satisfactorily in small plants, owing principally to the fact that repairs are few and simple, and that no skill is required in their use. Some direct-acting steam-pumps have given much trouble, as the steam-cylinders were too large in proportion to the water-cylinder for lifts of between 10 and 15 feet. For large works centrifugal-pumps are to be recommended, especially when the solution has to be pumped on to the tailings, as this requires to be done as quickly as possible. Piping arrangements, which in early practice were of defective design and bad construction, have now been reduced to great simplicity as follows:—One large pipe, connecting, with separate cocks, all the solution-tanks to all the leaching-vats (through a powerful pump when the former are below the latter), suffices to throw on all the solutions in succession. Separate drain-pipes from each leaching-vat are led to a convenient point where cocks are placed, and from which a short hose will reach to any of the zinc-boxes. These separate pipes are necessary because filtration from the vats is continuous for many hours, and the different solutions cannot be mixed. Separate pipes from the precipitation-boxes to the solution-tanks, with or without pumps, according to their relative levels, are provided. As an instance of simplification in more recent works it may be mentioned that in a 15,000-ton plant built ten months ago twenty cocks were sufficient, while in a 10,000-ton plant built two years ago there are over two hundred and fifty cocks. Iron

plug-cocks have been largely used, but are unsuitable because the caustic-potash, resulting from the decomposition of potassium cyanide, dissolves the film of oil in which the plug turns, with consequent leakage. Therefore the only valve to be used with safety is that of the packed cased type, such as the well-known Peet valve. The following are suitable sizes for the charging- and leaching-pipes :—

Diameter of Vats.	Diameter of Charging-Pipes.	Diameter of Leaching-Pipes.
Feet.	Inches.	Inches.
20–24	2½	1¼
24–32	3	1½
32–40	4	2

Preparation of Material.

It has been customary from almost the commencement of mining in the Rand district, after passing the battery-pulp over amalgamated plates, to run it into large shallow reservoirs, formed generally on a hill-side by an earthen dam, with an overflow outlet for the water to escape after being cleared by the settlement of the sand and slime in suspension, and of sufficient area to effect such settlement. This arrangement, known as the "tailing-dam," has the following results :—

The heavier grains of sand are deposited first near the inlet of the dam, then the lighter particles in fairly regular sequence, and finally the finest slimes which settle in the pond of comparatively still water on the side of the reservoir near the outlet. After the dam has been filled and drained dry, in some parts clean coarse sand is found alone, then usually finer sand with clearly marked layers of slime, and almost invariably the lower side is a solid mass of settled slime showing the horizontal stratification due to its method of deposition, with sometimes thin layers of sand interposed. Much of this slime possesses the plastic properties of clay and is consequently unleachable, but it has further disadvantages. If lumps of dry slime are treated with sand, the solution, as it dissolves gold from the sand, soaks into the dry slime-lumps and remains there after the rest of the material has been drained dry. Consequently it is a common occurrence for slime-lumps to assay higher after treatment than before, and it is therefore important to prevent such lumps entering the vat in a dry state. If they

contain at first as much water as they can absorb, no harm will be done, but at the same time nothing can be extracted from them. As this is purely a mechanical difficulty, it is from the engineer rather than the chemist that the remedy must come, and an account of some attempts that have been made to render mixtures of sand and slime-lumps suitable for leaching may be of interest.

By ploughing, harrowing, and shovelling through standing screens, dry slimes have been brought to fine powder, and, by mixing sparingly in the vats with plenty of sand, have been successfully treated so far as extraction is concerned; but the cost of this treatment is large. This plan was followed by the introduction of a disintegrator, first used for tailings which had been lying for years in a spruit, or small stream, and had been overgrown with grass to such an extent that they were dug out as sods consisting of grass, black soil and tailings. The machine used was designed and manufactured, principally of wrought-iron, on the spot. It has two disks studded with strong steel pins arranged in concentric circles. One disk is fixed, while the other rotates, and the space between them is closed by a circular casing attached to the rim of the fixed disk, with a hopper at the top and an opening at the bottom leading to a bucket-elevator. The elevator delivers into a cylindrical revolving screen with jets of water playing on the outside. The treatment was perfectly successful in that it tore the sods to shreds, broke up the slime-lumps, and separated the greater part of the grass roots and organic matter, and, with the addition of washing-vats, which will be described hereafter, enabled a quantity of rich tailings to be treated which otherwise would have been worthless. A larger and well-made disintegrator, manufactured by the Krupp Grusonwerk Company, of Magdeburg, has also been used, in which there are two cages revolving in opposite directions within a stationary casing. When the ratio of the slime to the sand is small, the action of the disintegrator, with the subsequent manipulation for transport to the vats, ensures a good leachable product without the use of a screen, but with a large ratio of slime to sand the product is almost unleachable. A more complete method of preparing such material, or of separating from it the portion amenable to treatment, will be better understood after the next division of the subject is considered.

Treatment of Pulp direct from Batteries.—It is of course advantageous to deal with all tailings directly they leave the battery, instead of storing them in the dams previously described, for the stored tailings represent valuable material lying idle, they are subject to heavy loss from wind and sometimes from floods, and

they are liable to the decomposition of the contained iron pyrites, which renders them acid and more expensive to treat.

A large amount of work has been done in this direction, of which only a brief account can here be given. The first method adopted in practice was the formation of rectangular pits a few feet deep, with movable weirs at their lower ends farthest from the inlet. A gentle downward slope of the bottom ensures a fairly uniform flow. The pulp is run through these pits, and when it leaves the narrow trough for the broader pit the immediate reduction of velocity causes the deposition of all the heavier sand, while the lighter portions flow away with the water. The tailings from a 60-stamp mill are passed through pits 120 feet long and 20 feet wide. As the level of the sand rises the overflow-level is also raised a few inches at a time. With pits of this length all the slime and, unfortunately, much of the fine sand flows away, while if the pits are too long layers of slime occur as in the tailing-dams, and constitute a serious drawback to what is nevertheless a good temporary expedient for catching the tailings for treatment.

In some of the works previously referred to, this method has been adopted for the purpose of direct filling into leaching-tanks. These tanks are square with side-discharge doors, as already described. Vertical grooved pieces are provided at each of the overflow apertures, and the overflow-level is gradually raised as the tank fills with sand by placing narrow strips of wood across the aperture, one above the other, in the grooves. The distribution of the pulp over the area of the tank is effected by a native labourer, who, with a flexible hose, directs the stream to the different parts as required. The principal objection to this direct filling is that the sand, when brought in by water, packs very closely together and the leaching is retarded, especially if much slime is collected with the sand. There is also the liability of the slime to collect in layers, and it appears at present to be necessary either to reject a large portion of slime and fine sand, or to deal with a very slowly leaching material.

For these reasons the Authors, in conjunction with Captain Mein, instead of experimenting further in the direction of direct filling, had previously worked out a system of treatment of the tailings direct from batteries by catching them in what are now generally termed "collecting-vats." The essential advantages of these are, a good distribution of the pulp over the whole area of the vat, a steady outflow over the whole periphery of the vat, and an easy means of transfer of the collected product to the leaching-vats. Wooden vats are usually fitted with filters and

bottom-discharge doors, and having a trough fixed round the top to catch the peripheral overflow, and deliver it into launders leading to the slime-pits. The best form of distributor, Plate 1, Fig. 5, consists of a central casting, carrying a conical receiving hopper, and a number of radial pipes, keyed on to a vertical spindle, which bears on a slightly convex steel pin in the bottom of a second casting bored to fit the spindle. Coarse wire-screening is fixed over the hopper to keep stones and rubbish from entering the pipes. The pipes are of different lengths, and each is fitted with a bend in order to produce automatic revolution of the apparatus, with a flattened nozzle to spread the pulp into a wide stream. The pulp is consequently delivered in a number of concentric circles, as many as are desired, the object being to obtain a uniform mixture of the material in every part of the tank, because with great uniformity a large part of the slimes can be caught without obtaining an unleachable product, more especially when the product is transferred to another vat for treatment. It cannot be too strongly urged that the gain by transfer is twofold, first, a better mixture is secured by shovelling into trucks and tipping; and secondly, the leaching-vat is filled with a light porous and quickly-leached material instead of a closely-packed mass through which solutions can run but slowly. The twofold gain, of higher extraction and increased percentage of slime caught for immediate treatment, more than compensates for the cost of removal. Even for filling direct into leaching-vats, the circular form with distributor and peripheral overflow gives a more leachable product than rectangular tanks with a few points of overflow. When a good slime-treatment process is devised, probably all slimy material will be separated from the sand, in which case it may be worth while to treat the latter in the collecting-vats without removal, but this is only a possibility of the future. The percentage of slime caught depends largely upon the diameter of the vat relatively to the quantity of pulp entering, for it is evident that a given quantity of pulp will cause more disturbance and have a greater overflow in a small vat than in a large one.

The following sizes have been found in practice to be effective with the usual character of clean quartz rock free from magnesium silicate:—

For 25 stamps	. . . . .	20 feet diameter.	
„ 50	„	24	„ „
„ 100	„	32	„ „

The depth of a vat does not appear to be of great importance, depending chiefly on the available fall in each case. For exceptionally slimy material, such as the decomposed free milling ore found in the upper levels along the Main Reef, vats of smaller diameters must be used.

Treatment of Slimes.—This is a question of the greatest importance, as at present there are many hundreds of thousands of tons of unleachable material lying useless on the hands of various companies. A brief account of the trials already made may serve to prevent waste of time on methods which have already proved unsuitable. The slimes have been made into bricks, which, after being burnt to render them porous, were broken up into small pieces, and treated in the same way as sand; but the cost was too great, and the method was abandoned. Another method consists of treating the material in barrels or in vessels with agitators, and extracting the gold-bearing solutions by filter-presses. This method has proved successful, but its commercial value has yet to be demonstrated. The only process which has yet produced economical results is that of treating the slimes in vessels with agitators, alternately agitating and allowing the slimes to settle, and separating solution by decantation after each settling.

The "Main Reef" Works.

These works, built in April 1893, were designed to treat 7,000 tons per month of tailings purchased from several companies in the neighbourhood, some of the material being carried over 2 miles. As will be seen from Figs. 1, Plate 1, there are six leaching-vats, each 26 feet inside diameter, with 8-foot staves, and holding 135 tons, estimated at 26 cubic feet per ton. There are also four solution-vats, 20 feet in diameter with 9-foot 6-inch staves, each holding 105 tons, and four zinc-boxes for precipitation, each 18 feet long and 2 feet 6 inches wide by 2 feet 3 inches deep. The amount of solution passing through each box per hour is about 5½ tons. The section on AA, Figs. 1, shows the excavation necessary to give the relative levels arranged so that the solutions gravitate to the leaching-vats, and through the zinc-boxes into small sumps sunk below the floor. From these sumps, two 5-inch Tangye steam-pumps and two 4-inch donkey-pumps lift them back to the solution-tanks, thus completing the cycle of operations.

The water is supplied by the Main Reef Gold Mining Company from a small reservoir some distance above the works. This

plant treats material under two separate contracts—hence the necessity for four solution-tanks, in order to keep two strong solutions and two weak solutions quite separate; and hence also the necessity for four zinc-boxes, in order to keep the precipitated gold separate, this being simpler, safer, and more convenient than working alternatively on the two materials with the same boxes. In ordinary cases two zinc-boxes would be sufficient to precipitate 270 tons of solution per day. The leaching-vats do not require to be duplicated, as the small amount of solution remaining in them after each charge of tailings may be disregarded. The section of the tunnel under the vat, 4 feet wide at the bottom, 5 feet wide at the top and 6 feet deep, is the smallest in which it is convenient to work, with the side-tipping trucks generally in use, especially with mule traction. The dump-line is parallel to the tunnel-line, and is connected to it by curves at each end, as shown in the plan, so that a continuous train of trucks passes under the vats out at one end of the tunnel, round the dump, and back again to the other end of the tunnel. A down gradient of 1 in 100 is given in each direction from the centre of the tanks to the ends, which provides for drainage and reduces the pull on the mules when starting loaded trucks. The lines for filling are also arranged for continuous work, whether the material arrives from east or west.

In considering the details of construction, it is necessary to point out that until quite recently the only timber obtainable with certainty in large quantities, in Johannesburg or at the ports, consisted of clear pine in planks, pitch-pine in logs to 18 inches square and 36 feet long, and Baltic deals 9 inches by 3 inches between 9 feet and 28 feet in length, the longest being very scarce. Small quantities of timber 11-inch by 3-inch, 9-inch by 4-inch, and 7-inch by 2-inch can sometimes be obtained, but only at a higher relative price, owing to the absence of competition in any but the usual sizes. Hence every dimension has to be suitable for cutting from 9-inch by 3-inch deals or from logs. The recent introduction of Oregon pine from America, and Karri from Australia, is already producing good results.

Construction of Vats.—The staves of the vats are $4\frac{1}{2}$ inches wide and 3 inches thick, and are planed to the bevel by machine and are afterwards hand-dressed on the abutting edges. They are checked $\frac{3}{4}$ inch to fit on the bottom with a chime 6 inches below the check. The bottom is made of 9-inch by 3-inch deals planed by machine and grooved $\frac{3}{8}$-inch by $\frac{1}{2}$-inch by a drunken saw, and is also hand-dressed on the edges. Clear-pine tongues 1-inch by $\frac{3}{8}$-inch fill the grooves. The joists across the tunnel consist of 9-inch by

3-inch deals, bolted together in pairs, laid 2 feet 3 inches from centre to centre.

These joists are first placed in position, then the bottom is laid down, cramped up, and the circle struck out. It is sawn to the circle, bevelled all round, and is then ready for the staves, which are driven up as tightly as possible. The six hoops are of round iron, the top pair of 1-inch, the middle pair of $1\frac{1}{8}$-inch, and the lowest pair of $1\frac{1}{4}$-inch diameter, with $1\frac{1}{4}$-inch screwed ends. Each is made in three sections, rolled to the required curve, and connected by castings of the form shown in Figs. 10. The screwed ends of the sections pass through the boxes, and while each hoop is being drawn up it is hammered with a heavy sledge-hammer. Two carpenters practised at the work can dress the material for one such vat 28 feet by 8 feet in about five days, and erect it in about four days. The cost of such vats, in pounds sterling, can be estimated, when the cost of three sizes is known, by the formula:

$$A \times B\, d\, l \times C\, d^2$$

Where A, B and C are constants, l the length of the staves, and d the diameter of the vat in feet. In Johannesburg at present prices, and to include filter-cloth and filter, the constants are 3, 0·5, 0·17 respectively.

The filter-frame is formed of slats, 3 inches by 1 inch, placed on edge 6 inches apart, their ends being kept 1 inch from the side of the vat; strips, 1 inch square and 1 inch apart, are nailed across on the top of these, to form a support for a filter-cloth of cocoa matting. The wooden filter is cut into quadrants for convenience in lifting. The gangway over the vats is carried on 9-inch by 3-inch deals placed on edge, the number varying according to the length of the span. Across the bearers and at right-angles to them are nailed wooden strips, 3 inches by $2\frac{1}{4}$ inches by 6 feet, with $2\frac{1}{4}$-inch spaces between them, thus forming a gridiron platform having sufficient width for working trucks with safety and at the same time allowing tailings to fall through it into the vats. The construction of a zinc-box is shown in Figs. 8. The sides and ends are of $1\frac{1}{2}$-inch deal, grooved and tongued, with 3-inch square pieces along the top and bottom to stiffen it and to receive the upright bolts along the sides, and also the bolts under the bottom. The partitions are of 1-inch clear pine, the joints being made watertight by fillets in the angles. The ends of the box are let into grooves in the sides and bottom.

The sizes of piping used are, between the solution and the leaching-vats 3 inches, for leaching $1\frac{3}{4}$ inch, and for throwing

back the solutions 2½ inches. An 8-HP. portable boiler provides all the steam required; but about 4 HP. is sufficient for ordinary work.

The "Princess" Works.

These works, Figs. 2, Plate 1, were designed by the Authors, in conjunction with Mr. Frank Spencer and Mr. A. A. Bradley, of the Princess Gold Mining Company, and have a capacity of 3,000 tons per month. They are interesting as showing the use of collecting-vats where the favourable site allowed of a very compact plant. The fall of the ground averages 4·2 in 100, and as tailings flow readily in a launder with an inclination of 3 in 100, the distance of 750 feet from the battery brings the launder 9 feet above the ground-level at the works. Two collecting-vats, 20 feet in diameter with 7-foot staves, are placed on a level with the surface over a tunnel lined with masonry. A small excavation suffices to place the leaching-vats low enough to give a level run from this tunnel to the gangway over them. The tunnel under the leaching-vats runs out to the ground-level in 120 feet, and consequently the filling and emptying is effected very economically, while the dumping-ground for residues is practically unlimited. The three leaching-vats are 20 feet in diameter with 10-foot staves; the three solution-vats are 16 feet in diameter with 9-foot staves; and the two zinc-boxes are the same as those in use at the Main Reef works. There being a considerable quantity of argillaceous material amongst the crushed ore, the products of the collecting-vats contain an exceptionally large amount of slime, and some difficulty was experienced at first in draining it; but by introducing during filling an additional supply of clear water at the bottom of the tank and percolating upwards through the filter, together with the use of a 1-inch suction-pipe with a fall of 20 feet, attached to the outlet below the filter during drainage, this difficulty has been successfully overcome. A second filter-cloth of jute above the cocoa-matting is used to prevent the solid material being drawn by suction through the coarse mesh of the latter material.

The "Simmer and Jack" Works.

The Simmer and Jack works, of a capacity of 15,000 tons per month, form an illustration of a large plant on a bad site, the ground being nearly flat, the space for residues being limited, and the tailings to be treated being scattered about, a part

amounting to 40,000 tons being cut off from the works by the Netherlands railway which passes alongside them. There is a small culvert under the railway, which was formerly used to run the tailings from the Simmer battery to the dams, and which is now utilized for feeding the collecting-vats from the battery. As no fall was available it was necessary to lift the tailings or the residues, and, rock being struck within a foot of the surface, it was decided to place the leaching-vats on a line of stone piers with the solution-vats and shed alongside, as shown in Figs. 3, Plate 1. A double gangway runs over the vats for filling, with inclined platforms carried on trestles at each end. The bulk of the material originally purchased lay at the south end of the works, and that incline was built first while a hauling-engine was placed at the north end. A downward slope from north to south was given to the gangway over the vats to facilitate the return of the empty trucks. The inclines at the north end, added afterwards, are worked by the same engine, sometimes one line being worked and sometimes the other. When being pulled from the north end the empty trucks have to run on an upward slope on the platform, but as they are pulled back by the engine this is no objection. The leaching-tanks are the largest wooden tanks on the Rand gold-fields, each holding 600 tons, being 40 feet in diameter, with 14-foot staves, the staves as well as the bottom being of 9-inch by 3-inch material.

The number of hoops necessary was calculated on the following basis. When the tanks are full of water the contents form practically a quicksand and may be assumed to act as a fluid. As regards the pressure produced, taking the weight of the sand at 90 lbs. per cubic foot and of the water at 20 lbs., the pressures were calculated for a fluid weighing 110 lbs. per cubic foot, which gives a total bursting-pressure of 85 tons, and on the lowest foot a pressure of 13 tons. There is also the swelling of the bottom to be provided for, but in these large vats the bottom was screwed down to the joists with screws spaced 2 feet apart along each joist. Each vat has eight discharge-doors disposed as follows. The centre line is laid down and the semicircle on each side of it is divided into two equal areas by a line parallel to the centre line, which is therefore at a distance of two-fifths of the radius from it. The two lines so obtained give the centre lines of the two rows of doors, and therefore of the two tunnels through the masonry piers. The semicircle is then divided lengthwise into four equal areas, and the centre of gravity of each is the proper position for a door. In practice the points so obtained are altered slightly to make the

openings equidistant. Plans and section of a discharge-door are shown in Figs. 6. A circular hole, 16 inches in diameter, is cut in the tank-bottom; above this is placed a flanged tube of the same diameter, and 7 inches high, and below the wood a cast flange with a turned face on the under side of it. The two flanges are bolted together through the wood. A tee-bolt rests on snugs cast on the tube and passes through a central hole in the cover, which is screwed up in place by a butterfly-nut on the tee-bolt. The tube is then filled with waste sand and a slab of well-worked clay pressed down over the top of it. As it is dangerous to dig a small hole down through 12 feet of sand, the difficulty is obviated by the use of removable slotted tubes in short lengths of 2 feet, which are placed above half the doors reaching to about 6 feet from the top of the tank. The tank is then ready for filling, which takes usually about ten hours. It can be emptied in nine hours by sixteen Kaffirs working inside, with twenty mules, trucks and drivers, on a discharging-line 650 yards long. The three solution-vats are each 26 feet in diameter, with 15-foot staves, and are constructed in the manner previously described. In making hoops for these, water-pressure only has to be provided for. There are four zinc-boxes, each 24 feet long, 3 feet wide, and 2 feet 3 inches deep, constructed similarly to those at the Main Reef works. One 4-inch Tangye centrifugal pump throws all the solution from the storage tanks to the leaching-vats. From the latter it runs through the zinc-boxes into cement-lined brick sumps, the top of which are level with the tops of the zinc-boxes. A 2-inch centrifugal pump is connected to each sump and kept working. It is placed so low that when the sump is nearly full the pump is filled up, and so automatically starts pumping, which it continues until the sump is empty. A very small pipe connected to the top of the case of the pump and overflowing into the sump renders the action more certain, by allowing the air to escape. A 6-HP. Tangye "Colonial" engine drives the four centrifugal-pumps, in addition to two lathes for producing zinc turnings for precipitation, and a small ball-mill for grinding lime. This engine, together with one 8-, one 10-, and one 12-HP. hauling-engine is fed by one Ruston-Proctor 60-HP. return-tube boiler. Two small vats, 9 feet in diameter with 6-foot 6-inch staves, and one 7 feet by 4 feet, are provided for use in cleaning up the gold.

When cleaning up the gold, the cyanide liquor in the zinc-boxes is first displaced by clean water. The zinc is then removed, being first carefully washed in the box, thus allowing

all fine zinc and gold to fall to the bottom; the greater part of the water is then pumped into the two 9-foot vats, to allow of the settlement of any fine gold which may be brought away with it. The remaining water is pumped into the smallest vat, leaving at the bottom of each compartment a quantity of precipitated gold, mixed with zinc in fine powder and small fragments. The mixture is carefully scraped and mopped up, and is washed through a fine screen into the small clean-up vat, the object of the screen being to eliminate the coarse pieces of zinc and any rubbish. A few pounds of alum are added to the small vat, and its contents are allowed between twenty-four and forty-eight hours to settle. Then the water is carefully decanted off until the slime begins to come with it. The remaining pulp, of water, gold, and zinc, is run into iron drums and sent to the smelting-department; where it is first roasted in a special calcining furnace to oxidise the zinc, after which the roasted material is smelted in the ordinary way.

The special furnace for roasting slimes, shown in Figs. 7, is a combined reverberatory- and muffle-furnace. There is a fire-box at one end, a cast-iron hearth in the middle on which the material lies, and an exit-flue at the other end. The fire-bridge is built in two parts, with a passage between them, leading to flues below the cast-iron plate, so that part of the heat and products of combustion are deflected and pass under the plate, while the remainder passes over it with plenty of air, thus effecting the oxidation of nearly all the zinc.

The "Worcester" Works.

The last example for illustration is the cyanide works of the Worcester Gold Mining Company, Figs. 4, Plate 1, where the electrical process of Messrs. Siemens and Halske was first introduced on a commercial scale by the Rand Central Ore Reduction Company, under the supervision of Mr. A. von Geruet. There are five leaching-vats placed on a row of stone piers with a single tunnel beneath. Each vat is 20 feet in diameter, with 10-foot staves, and is of 100 tons capacity. Between the vats and the precipitation-boxes there are placed two tanks, 16 feet in diameter, with 6-foot staves, forming two intermediate reservoirs, in order to enable the flow through the precipitation-boxes to be kept constant, a matter which is very important. A better method now being introduced to secure the even flow, is to pump all the solution into a small raised tank provided with an overflow into the intermediate tank,

and a delivery-pipe to the precipitation-boxes. The small tank is kept always full to overflowing, so that it delivers under a constant head. In an excavation beyond the boxes there are two storage-tanks, 20 feet in diameter, with 6-foot staves, from whence the solutions are returned to the leaching-vats.

Two collecting-vats, 20 feet in diameter, with 8-foot staves, are installed and receive the tailings from the 25-stamp battery of the Worcester Gold Mining Company. There are four electrical precipitation-boxes, the construction of which is shown in Figs. 9. They are 18 feet long, 7 feet wide, and 4 feet deep. Each contains eighty-nine iron-plate anodes, 7 feet by 3 feet by $\frac{1}{8}$-inch (cased in canvas to retain the small quantity of Prussian-blue produced), and eighty-eight cathodes of lead-foil stretched on wires fixed in a wooden frame. Each frame contains three strips, 3 feet by 2 feet, so that, counting the double surface of each lead sheet, there are altogether about 3,000 square feet of cathode surface, the current density being 0·05 ampere per square foot. The boxes are made of 3-inch material throughout, with stiffening pieces across the sides and bottom. The divisions are of wood or are formed by raising some of the iron plates a little above the level of the liquid, while others are placed down on the bottom, the joints being made watertight by wooden fillets caulked with hemp packing. In cleaning up the gold by this process the frames are taken out singly, and the lead-foil is removed and replaced by fresh lead-foil when sufficient gold has been precipitated on it. All that is necessary afterwards is to smelt the lead and finally cupel it, thereby obtaining clean gold, alloyed however with 10 per cent. of silver.

A 20-HP. Robey semi-portable boiler supplies steam for hauling, pumping, precipitation, and lighting, supplying a 10-HP. hauling-engine and an 8-HP. horizontal engine which drives a Siemens-Halske dynamo, giving 300 amperes at 10 volts, a small dynamo for lighting, and a 4-inch centrifugal-pump. Only 4 HP. is consumed in precipitating 100 tons of solution in twenty-four hours.

In conclusion, the Authors desire to express their thanks to the Directors of the Rand Central Ore Reduction Co., for their kindness in assenting to the publication of the plans and information contained in the Paper, and to the engineering staff of the Company for the assistance they have rendered.

The Paper is accompanied by five photographs and nine tracings, from which Plate 1 has been prepared.

Discussion.

Sir Douglas Fox.

Sir DOUGLAS FOX, Vice-President, was sure it would be the desire of the Institution to pass a hearty vote of thanks to Messrs. Butters and Smart for their interesting communication. It was one which had reminded him of a visit he paid to California, in the year 1858, when he well remembered the excessive waste that took place at the gold quartz mines in connection with the tailings. It was said that the processes which had been described were likely to bring about a complete revolution in the gold-washing industry, so that thanks were especially due to the Authors.

Mr. Smart.

Mr. EDGAR SMART wished, before the discussion was opened, to ask for information upon one or two points. At the mines it was necessary to take the apparatus as handed over by the importers, and, as a rule, it was not possible to obtain everything that was wanted. For instance, in the matter of trucks, the use of the ordinary V-shaped truck was compulsory, with the result that, in handling wet tailings, when the truck was tipped, the material stuck inside it. It had therefore to be prized out with iron bars, and was finally tipped as a solid lump, somewhat in the way that blanc-mange came out of a mould. If a truck could be produced suitable for the transport and tipping of wet tailings, a great benefit would be conferred upon engineers generally, and particularly upon all who were engaged in handling the tailings.

Mr. Moreing.

Mr. C. A. MOREING said the cyanide process was particularly a metallurgical matter, and one which metallurgists would be more capable of discussing than he was. One thing which had occurred to him in listening to the Paper had been that a great part of it was devoted to the question of slime, and the difficulty incurred from it in the tailings. It would seem that the best way of overcoming that difficulty would be not to make slime, or to make as little as possible of it in the treatment of the ore. The cause of so large an amount of slime was undoubtedly the stamp-mill, which pounded the ore into very fine particles, and continued pounding it after it was completely pulverised. Where the cyanide process was to be used, some method of reducing the ores should be attempted other than by the stamp-mills. Unfortunately, at the Rand, all the mines were employing stamp-

batteries; and the inventors of the cyanide process, and those engineers who, like the Authors, had so ably carried out the details of that process, had to contend with the conditions as they found them at the Rand. It appeared to him that in new districts, where engineers had an opportunity of profiting by the experience of those who had preceded them, some other method of crushing ores should be adopted, by which the ore would not be pulverised into slimes, as was the case with the stamp-mill. There was no doubt that the invention of the cyanide process had revolutionised the gold mining industry as it was known a few years ago; and it was likely to lead to an enormous production of gold in the future—quite impossible of attainment before that process was invented or, more correctly, brought to practical use, as it had been by Mr. J. S. McArthur and Dr. R. W. Forrest. The Paper was full of practical details which would be of great assistance to all engineers who had these problems brought under their observation, and who had to deal with them in other parts of the world. Owing to its success with Johannesburg ores, the cyanide process had been introduced into nearly every country in the world. It was making great progress, and would probably in the course of a few years be the means of largely increasing the world's store of gold. Mr. Moreing.

Mr. R. J. FRECHVILLE, having returned from Johannesburg a few months ago, could bear testimony to the excellent exposition of the mechanical appliances for treating tailings by cyanide as given in the Paper. It had been stated by the Authors that "when a good slime-treatment process is devised, probably all slimy material will be separated from the sand, in which case it may be worth while to treat the latter in the collecting-vats without removal, but this is only a possibility of the future." That had long been appreciated in Johannesburg. Slime, in connection with sand, was most disadvantageous to the process of treating by cyanide. This had been seen some two years ago by Mr. Hennen Jennings, the consulting engineer to Messrs. Wernher, Beit & Co., who had resolved not to treat slime and sand together. Therefore, at the Heriot and the City and Suburban mines he had arranged that after the pulp or crushed material left the ends of the copper plates, it was conducted into "spitz-kasten," pointed boxes with an upward flow of water, such as were used in ore-dressing works on the continent of Europe, and the sands were there separated from the slimes. The latter were saved in reservoirs for future treatment, whilst the sands passed directly into collecting-vats, in which they were Mr. Frechville.

Mr. Frechville. subsequently leached by cyanide, all the manual labour of filling these vats being thus avoided. It was supposed that there would be a disadvantage in this method of filling the vats, owing to the sands packing and proving impermeable to the cyanide solution. In practice, however, it was found that if free from slimes the solutions percolated at a fair rate through the sands, although they took a somewhat longer time to do so than in vats filled in the ordinary way. Better results, as to extraction of gold, saving of cyanide and costs, were stated by Mr. Jennings to be obtained by his method of direct treatment, as the sands did not come into contact with the air, thus avoiding the oxidation of the pyrites and formation of acid, with consequent destruction of cyanide, which occurred in the ordinary method of filling the vats by manual labour. When Mr. Frechville left Johannesburg some few months ago, it was stated by Mr. Butters that his method of using intermediate vats enabled nearly 90 per cent. of the ore stamped to be treated. That was certainly an argument in favour of his method. It had always been maintained by Mr. Jennings that he was not losing the slimes, but was merely storing them for a future method of treatment that would soon be discovered. His anticipations appeared to have been realized, as Mr. Lionel Phillips, President of the Johannesburg Chamber of Mines, was reported to have stated in January 1895 that the Robinson Gold Mining Company were erecting works for treating 8,000 tons of slimes a month. He did not know what process was to be used, or how the works were designed; but apparently, even since he had left Johannesburg, a method of treating the slimes had been discovered, and he was certain that nothing would be done by the Robinson Company that was not thoroughly practical, and that they would not proceed to erect such large works without being fully assured of the result. It would, therefore, be seen that the possibility indicated in the Paper appeared already to have been accomplished, since a method had been found of dealing with the slimes in a manner in which they had not been dealt with previously.

Mr. Vautin. Mr. CLAUDE VAUTIN had listened with great interest to the Paper, which was to him a most excellent illustration of the value of the co-operation of the chemist or metallurgist with the engineer. Every credit was due to the engineers who had erected the plant for carrying out the process on the Rand. This was the first time in the history of the extraction of gold that such enormous quantities of gold-bearing material had been treated by the wet process; that was to say, in which gold had been

removed in the form of solution. He should have been glad if the Authors had given a few additional details as to the construction of the leaching-vats; and it would be interesting to know the method generally adopted on the Rand, more particularly by Mr. Butters, of attaching the cocoanut-fibre, or whatever filtering medium was used, to the side of the wooden vat. He would like to ask Mr. Smart to express an opinion as to the relative value, as to cost and the percentage of gold extracted, and as to the facility of working, on the one hand, of the process of decomposing the double cyanide of gold and potassium by metallic zinc; and, on the other hand, of the Siemens-Halske electrical process. He would not in any instance accept complicated instead of simple processes to bring about probably the same result. He would like to have the Authors' opinion as to the relative value of the two methods, one in which the solution was passed through a vat of so complicated a structure as that at the Worcester Works, Figs. 9, Plate 1, the gold having to be passed on to the lead-foil, and the lead melted and cupelled, which was not an easy operation and entailed a special establishment; and, on the other hand, the method of passing the solution simply through zinc, as originally devised by Mr. McArthur. The information would be most interesting to everyone connected with the subject of gold extraction by the cyanide process. The method of joining hoops shown in Fig. 10, was that generally used for vats when treating copper or gold ores by leaching or wet processes. There was one novelty shown in the interesting form of furnaces for calcining, which could at pleasure be converted into a muffle or a reverberatory furnace. He was sure everyone interested in the extraction of gold would wish to do away with the stamp battery; but if it were determined to use the cyanide process as one means of recovering gold, it was most desirable that the coarse portions of the gold contained in the ore should be removed previously to treating the remainder of the ore by means of cyanide. He doubted whether, at present, there was any practical method of treating such large quantities as were dealt with at the Rand, otherwise than by the stamp-battery. This had the advantage of admitting of the pulp being passed over the plates and the removal of the coarse gold, which it was desirable should not be submitted to the action of cyanide, and then of the tailings being passed on for subsequent treatment. He quite agreed with the remarks made by Mr. Frechville as to the practice of removing the slimes from tailings at the Crown Works. The anticipation of Mr. Jennings that a satis-

Mr. Vautin.

Mr. Vautin. factory method of dealing with the slimes would sooner or later be arrived at, was justified and had already been realized.

Mr. Mactear. Mr. J. MACTEAR said there were two points to which he should like to refer, one as to the construction of the plant, and the other the cyanide process itself. The wooden tanks now adopted were precisely the same as those which had been used, he was afraid to say how long ago, in connection with the wet process of copper extraction. The details of the construction of those tanks were practically those of almost the first tank constructed for that purpose. There had also been in those days a method of making the joints of the wooden vats which did not seem to be known at the Rand, and perhaps not to the Authors. As information had been asked for, he would describe how those joints were made. A pair of small rollers, about 1 foot in diameter, were turned with a projecting rib around them of $\frac{1}{2}$ inch or $\frac{3}{4}$ inch in breadth, and about $\frac{1}{2}$ inch high. The planks used for making the staves of the tank were passed between these rollers under a considerable pressure, obtained by means of weights and levers, with the result that when the plank came through there was a groove from end to end in which the fibre of the wood was compressed to the depth of $\frac{1}{2}$ inch. The planks were then passed through the planing machine at such an angle as to suit the joint of the tank to be made, according to the circle of the tank, and what might be called the excess wood, or the two projecting portions, were planed away until the surface became level with the crushed fibre. Then the tank was built, and the result was that no sooner did the wood become wet than the fibre which had been crushed so severely began to expand, and a joint was obtained which was not equalled by any of the ordinary joints known at that time. To his certain knowledge tanks made in that way had been in use for twenty years. The method of discharging the tanks was one which had been used in the black-ash process for discharging the refuse through the bottom, and of course had served equally well then as now. The same difficulty that had arisen in connection with that substance seemed to arise in discharging from the wagons of which Mr. Smart had spoken. The wagons used at that time were square-bodied, hung on gudgeons, so that they could tip, and there was little difficulty in emptying them. Probably those wagons would be too large for the lines of rails and the general arrangements of the Rand Works; they held between 1 cubic yard and $1\frac{1}{2}$ cubic yard of material. He should like to have heard more as to the relative advantages of the two precipitating methods. Great advantage had been stated to result

from the electrical process of Messrs. Siemens and Halske, inasmuch as a weaker solution of cyanide was used, and zinc had not to be contended with, a purer bullion being ultimately obtained. From the description of the process by the Authors, and the drawings of the apparatus, with the multitudinous arrangements of the thin lead-foil sheets upon which the gold was precipitated, and in view of the fact that the lead had to be melted and cupelled, it appeared to him that a process was being introduced to which there were many objections, with comparatively few points in its favour; more particularly when it was found that in the residual liquors which passed away from the electrical precipitation-box, the gold remaining unprecipitated amounted to double what it was in the zinc-box in the present cyanide process. That of itself might or might not be a great difficulty and danger. It had been argued that as these solutions were used over and over again it did not matter; all the solutions had to come back again, and, as in the solution there could only be what might be called the normal stock of gold, although in the first operation 4 dwts. of gold might be left to a ton of solution, when it came round again still only 4 dwts. were left to the ton, and 100 per cent. of what was extracted from the ore in the second operation was obtained. That might be true, but every time the solution was circulated there was a certain amount of loss, and if so there must be a certain amount of loss of gold. That, of course, applied to both processes, but it was clear that if there was double the amount of gold in the one process to that in the other, there was likely to be a greater loss in the one than in the other. Precipitation by zinc was, he thought, the superior method, applied either as at present or by some mode in which the zinc would be more easily and readily eliminated from the bullion. With regard to the large vats which had been constructed of brick and cement in an excavation in the ground, he would under no circumstances adopt such an arrangement. There was in a case of that sort no means of ascertaining what leakage was going on, and in a process in which material so valuable as gold was being dealt with, an exceedingly small leak or hole might cause in the course of the year such leakage as would pay for the cost of the plant over and over again. He thought, therefore, the wooden tanks with all their disadvantages, and they had many, were to be preferred to the brick and cement tanks sunk in the ground. If brick and cement tanks were to be used, they should be built inside a brick and cement safe, in such a way that any leakage would be seen to run to the outside,

Mr. Mactear.

Mr. Mactear. and the loss could in that way be checked. He had bitter experience of the difficulties of tanks sunk in the ground and the leakages which took place from them: it was one of the most heart-breaking things to find losses going on with which there were no means of coping, and which could not be discovered. It was perhaps scarcely within the scope of the Paper, but it would have been interesting to know something of the loss of gold in the residuals and wastes passing away; in other words, the percentage of gold extracted and the loss of cyanide. The Paper dealt more particularly with the constructive part of the cyanide process, and was a most admirable one, giving an immense amount of information. It had been said by Mr. Moreing that one of the great difficulties was the question of slimes. It would not be satisfactory to crush an ordinary ore to a point at which it could be treated with cyanide, and then attempt to extract all the gold by cyanide. The cost and time of extraction would be so great as to render the process altogether inapplicable. In this regard he thought it was worth noticing that in all the statements and estimates of the cost of treatment by cyanide, there was given a statement of the cost of what might be called the cyanide treatment alone, that was to say, that the tailings or ores to be treated were delivered to the cyanide works practically free of cost. They had already been mined, had been crushed, had borne their share of all the installation and administrative charges, and the only cost placed against the gold extracted was the cost of cyanide and the cyanide process itself. It therefore became a most unfair comparison to contrast the cost of production of 1 ounce of gold by the cyanide process with that of producing the same quantity by the melting process: the two things were, in fact, not comparable. He felt inclined to take a strong exception to the statement that the cyanide process had revolutionised the gold industry. No doubt the cyanide process had been of immense service to the gold industry, but what had been of most service to the process was the discovery of Transvaal ores, prior to which the cyanide process could not be called a success; and even at the present day, with all the information gained in the Transvaal, he believed the amount of gold there produced was more than 90 per cent. of the whole production by the cyanide process. There were many ores not amenable to treatment by the present cyanide process, but the Transvaal ores were, though refractory to a certain extent in the ordinary acceptation of the term, highly amenable to cyanide treatment, and it was to that fact entirely that the great advantage of the process appeared to be

due. In regard to the question of hooping vats, he had found the use of iron chains more satisfactory than that of bars. By that means each plank received a due amount of support. Mr. Mactear.

Mr. WILLIAM S. LOCKHART asked for information as to the systems of concentration at work in the Rand. The large plants, shown in Plate 1, suggested that there was a very rich product to deal with, but when it was realized that about 95 per cent. of the material dealt with—and it was that 95 per cent. which required all this plant to be so large—was worthless, it would be interesting to know if something could be done, and he believed that something was being done, to reduce the quantity. Almost all the mechanical difficulties referred to were caused by the great size of the plant, but if concentration were adopted the size of the plant could be quickly reduced, and the details would then be much more simple. He had hoped that the Authors would have referred to concentration, because he knew that many of the keenest minds in the Rand were being exercised on that question. It was largely bound up with the slime question. With regard to slimes, it was stated in the Paper that it was from the engineer rather than from the chemist that the remedy must come. It was as an engineer and not as a chemist that he would approach it. He had about a year ago shown at the Institution a gold-concentrator, since perfected, by which he was able to take the pyrites out of the ores with a concentration of about 97 per cent., that was, 3 per cent. of pyrites containing the gold was separated from 97 per cent. of worthless quartz, the latter being found on assay to contain no gold. It would be interesting if Mr. Smart could state what other systems of concentration were in vogue. The question of the separation of the slimes from the products was, he thought, bound up in that of classification. The reason why percolation was so bad through many of the vats, was that all sizes of sand were put into the vats together, and the sand of the small sizes filled up the interstices between the grains of the large ones; whereas, if the particles were all of the same size, the percolation would be better. If the fine slimes were kept separate, much better percolation would be obtained. He agreed that the best method of avoiding the difficulty of treating slimes was not to make them. This was exactly what he advocated, and with a separator giving close concentration it would be possible to largely reduce the amount of slimes. For many ores, a screen of 20 meshes to the linear inch at the stamps would give Mr. Lockhart.

Mr. Lockhart. sufficiently fine crushing for the actual division of the gold or pyrites from the quartz. With a screen of this size the stamps would of course crush more ore per day, making at the same time less slimes. Plates might be dispensed with and valuable time saved, as there would be no need to stop the stamps for cleaning, nor would retorting for the recovery of the mercury be necessary. From the mortar-boxes the crushed quartz would pass direct to the hopper of a thoroughly efficient classifier, which would grade the crushings and drop each size into an automatic separator, adjusted to catch the gold and reject the tailings practically free of gold. When treating free-milling ores the process for the larger sizes down to, say, 100 meshes to the linear inch, might at this point be considered complete; and the finer sizes and slimes, if treated chemically, could also be first largely concentrated. If a mechanical process only were in use, the system of mechanical separation could be carried quite well down to, say, "paint-gold." For refractory ores, where a chemical process was essential, the separators would deliver the pyrites clean and carefully graded, so that out of, say, 100 tons of ore, only some 5 tons would have to be treated by cyanide, chlorination, or whatever process might be adopted. With so small an amount of material to be treated, these operations could be carried out with comparatively small plant, and the extraction would be relatively more complete. In the process under discussion, a saving of about 90 per cent. of the cyanide should be effected, and the cost of plant, standing expenses for labour, &c., proportionately reduced, while at the same time a larger yield of gold would be obtained. With the separator-plant referred to, all this could be easily accomplished.

The question of the bands of the vats had been referred to, and he thought that, instead of using round bars of different sizes such as these hoops were made of, it would have been simpler to have used more hoops of the same section, spaced somewhat more closely. It had been said that the question of choice of material was very important at the Rand; but if, say, 1-inch bars could easily be procured, it would surely be better to use all 1-inch bars, as the hoops would then be alike and the nuts interchangeable. It appeared to him that to use 1-inch, and $1\frac{1}{8}$-inch bars with $1\frac{1}{4}$-inch ends was an unnecessary complication, and especially the last, since the $1\frac{1}{4}$-inch ends would be a source of weakness rather than of strength, as they would have to be welded, and probably the weld would be weaker than the original bar. If the lower bars were placed closer together, they would probably

afford a better support generally to the vat, and at the same time all the bars being thinner would be more easily tightened up. The joint-boxes appeared to be short, independent castings; but he should have thought that had they been continuous, with holes pitched at the spacing decided upon, they would have given a better support to the tank from top to bottom. It had occurred to him, though he mentioned it only as a suggestion, that hooping with wire might be preferable. In centrifugal work it had been found almost impossible to give proper support to large baskets with bands, and he believed the best practice now was to wire them round under considerable tension. Mr. Lockhart.

Mr. Bertram Blount thought that in a case like that under discussion it behoved a chemist, amongst which class he ranked himself, to approach the subject with modesty, because, except for the fundamental principle of extracting gold by the solvent action of cyanide of potassium, the chemist had accomplished little. It was true that in the early stages of the process Messrs. McArthur and Forrest had shown that potassium cyanide not only had a solvent action upon gold—a fact which had long been known—but that that solvent action was sufficiently rapid to allow of the commercial application of the laboratory process. At that time, however, no one had the slightest conception that there would have been the advance that had since occurred in the application of the process to ores which were now yielding a large part of the world's gold supply. But from that it did not follow that the limit had been reached. It appeared to him that the process, even when carried out by engineers of great ability, and brought to such a state as had been shown in the Paper, had not become quite as perfect as could be desired. For example, the method of leaching out ore in individual vats, which were treated separately by a solvent solution of cyanide of potassium, left, it seemed to him, something to be desired. It was a truism that in all chemical processes it was eminently desirable that two things should be attained—first, that the process should be continuous, and, next, that it should be systematic. He did not understand from the description in the Paper that any attempt had been made to render the process other than discontinuous and unsystematic. It was possible that there might have been later developments than those given in the Paper, and that a systematic continuous process had been devised. If that were the case he should feel under a great obligation if the Authors would give some information on the subject, for in indicating such a process, they would describe something which was altogether Mr. Blount.

Mr. Blount. novel to many. If no such process existed, it was plainly a case where the ingenuity of the inventor might be profitably turned to account. He found that the treatment of slimes was a question which had received a great deal of attention, nevertheless with small result. He thought the term "slimes" was applied accurately to those somewhat argillaceous portions of the ore which defied the ordinary processes of extraction. According to modern practice these slimes were more or less segregated and separated from the rest of the constituents of the ore, which were more susceptible of ready treatment. He found a hint, but only a hint, that the slimes were of the nature of clay. If they were only finely crushed quartz, he could hardly conceive that any particular disadvantage, other than that due to their fineness, would be encountered in extracting them. If, however, as he presumed, the materials were other than crushed quartz—if they were argillaceous, possessing the well-known properties of ordinary silicates of alumina and substances of that kind, which were constituents of common clay, it was quite conceivable that the extraction might be exceedingly difficult. The fact that such extraction was difficult pointed strongly to slimes possessing a constitution such as he described; but he should like to know from the Authors whether that supposition was within the range of their experience, or whether the slimes were sharply differentiated from the rest of the ore by their possessing a more clay-like nature. Assuming that his question were answered in the affirmative, and that slimes were clay rather than sand, the question of their extraction was much simplified for consideration; but it was greatly complicated for execution. It was well known that clay was a difficult material to handle in contact with large volumes of water. When once it had attained a state of suspension it was loth to subside, and if it was desired to cause a large volume of liquid to percolate through a considerable stratum of clay, difficulties of a most unexpected description would be encountered. Those difficulties had been alluded to in several parts of the Paper. Speaking of the plant in operation at the Princess Works, the Authors had stated, "The three leaching-vats are 20 feet in diameter with 10-foot staves; the three solution-vats are 16 feet in diameter with 9-foot staves; and the two zinc-boxes are the same as those in use at the Main Reef works. There being a considerable quantity of argillaceous material amongst the crushed ore, the products of the collecting-vats contain an exceptionally large amount of slime, and some difficulty was experienced at first in draining it." That was not a question

of the treatment of slime, but a question of the treatment of the tailings containing slime; and even when the amount of slime in the tailings was exceptionally large, though not so large as to rank the tailings distinctly as slime, it was found that there was great difficulty in draining it. It might, therefore, be assumed that the treatment of slimes was much complicated by the fact of their consistency. As to the methods devised to overcome that trouble, the only process that seemed to have been to any extent adopted was that of separating the slimy materials from the rest of the tailings, and putting them aside in the hope that they might afterwards be more susceptible of extraction. It appeared to him that it would have been more courageous—he did not know whether it would have been more profitable or practical—to try to face the difficulty, and to treat the slimes as they stood. It was well known that when an argillaceous material was suspended in water it was caused to subside, and the handling of it was much facilitated by the addition to the water of a small amount of one of several salts. Ordinary clay suspended in water would remain in that state for a long time until it was dosed with, say, a minute percentage of acid or a soluble salt; and on being dosed in that way it subsided and became altogether more easy of treatment. But unfortunately a chemical difficulty supervened. If that obvious practice, the addition of a soluble salt or acid (he referred more particularly to an acid), was tried in the case of the cyanide extraction process, the chemical difficulty arising from the decomposition of the cyanide by the acid added would at once make itself felt; and it was the necessity of keeping the liquid in which the cyanide extraction was carried on neutral or alkaline which made it requisite to abandon that method. Other methods had to be resorted to. He was certain that the inventor of a method of treating slimes, whether by mechanical separation of the extracting liquid with which they were treated, or by so acting upon them as to render them more susceptible of extraction, would reap not only a large fortune for himself, but a considerable advantage to the industry throughout the Rand. The next point he wished to mention was the question of dealing with the presence of zinc in the liquors which came from the extraction of the gold. In the ordinary routine, the potassium-cyanide solutions were run through precipitating-boxes, and there the zinc, in accordance with the well-known behaviour of metals that were more strongly electro-positive than gold, expelled the gold from the cyanide solution, and the zinc itself went into solution in the place of gold. It followed that

Mr. Blount.

Mr. Blount. after repeated extractions (because the liquors were turned back into the leaching-vats after the first extraction was completed and the precipitation of the liquor had been effected) the zinc would tend to accumulate in the extracting liquors. He should like to hear from the Authors, who, no doubt, had practical experience of the process, whether they had found that the accumulation of zinc in the liquors in any way deteriorated them in regard to their extracting effect—in other words, whether they had found that the zinc cyanide was a less efficient extractor than potassium cyanide. There was no chemical reason to suppose that it would be seriously less, but, in such cases, practical experience must be taken as a guide; and he should be greatly indebted if the Authors would add to his knowledge in that respect. Another point arose when considering the utilization of considerable quantities of zinc for precipitating gold, viz., whether the quantity of zinc used in the precipitation was in accordance with its calculated chemical equivalent, or whether so large an amount of zinc remained as debris, along with the gold, as to make the final sludge collected rather more zinc than gold. He inclined to the opinion that such was the case; but whether it was of any practical importance perhaps the Authors would be able to state. Another point had reference to the ratio of potassium cyanide to the gold which it extracted. If the amount of potassium cyanide strictly necessary to dissolve the gold was calculated, it would be found that the amount was inconsiderable. Nevertheless, as a considerable quantity of cyanide was used, it followed that a large excess was always required. The reason for that excess was not at first sight obvious, but he thought, on a little inspection, it became plain. The reaction depicted by the familiar equation, representing the action of the potassium cyanide upon the gold, where the gold displaced the potassium and eventually the potassium appeared in the final liquors as hydroxide, indicated that the final product of the reaction was potassium hydroxide; this substance was still a tolerably energetic compound, and the scale of energy had not been sufficiently descended, so that the difference between what corresponded in the reaction with the difference between the upper and lower temperature of working of an ordinary steam-engine (if the rough analogy might be admitted) was but small. If the drop of voltage (adopting for the moment an electrical simile) were larger, it was readily conceivable that the reaction would proceed faster. He thought an endeavour had been made to meet that requirement by the addition of materials which would absorb the potash and lower

the further end of the scale of drop. One of the most obvious means for facilitating reactions of that kind consisted in supplying one of the reagents in larger amount—taking advantage, in short, of the effect of mass action. That might be done in the present instance by largely adding to the amount of air associated with potassium cyanide used in extraction; and it seemed to him that it would be well worth trying to ascertain whether aëration of liquors used for the extraction of ore would facilitate their effect upon the ore; or whether the limit had already been reached in the natural amount of oxygen retained in the liquors after contact with the air. An extension of the same idea arose in this way: that it was not indispensable to use a material like oxygen; an actual absorbent could be used for the potassium hydroxide which was formed. The most obvious absorbent was carbonic acid, but if that were used to saturate the end product of the reaction, it would be necessary to be particularly careful to avoid overstepping certain limits, because carbonic acid had a direct decomposing effect upon potassium cyanide, and, if the limit were exceeded, the active material, potassium cyanide, would be, by that very act, decomposed. Still it was possible to work within limits, and it was quite likely that those persons who had found certain drawbacks in the ordinary cyanide process had experimented in that direction, and no doubt their experience would greatly add to the knowledge gained of the subject. Another point was connected with the precipitation of the gold as distinct from its extraction. He gathered from the Paper that two processes were in operation, one consisting in the direct action of zinc upon potassium cyanide solution containing gold, the other being the method devised by Siemens and Halske of precipitating gold by a current of electricity passed between a number of anodes and kathodes arranged in a long line in a precipitating cell. In the present instance the kathodes were made of lead, and gold was precipitated upon them, lead being undoubtedly selected because it was a metal which could be separated from gold by the subsequent process of cupellation with remarkable ease. The anodes, on the other hand, were made of a metal which was at once cheap and not readily attacked in an alkaline solution, viz., iron. The process was beautiful in its simplicity of reaction, but in its complication of plant it seemed to him that it left a good deal to be desired. One of the diagrams exhibited a large number of plates, all in close proximity to one another—and necessarily so, in order to avoid the consumption of an amount of current altogether incommensurate with the quantity of gold thrown

Mr. Blount.

Mr. Blount. down—and it appeared to him that there was a considerable risk of difficulties arising from the number and close approximation of those plates, and further, that, in the event of the action of the cyanide solution upon the iron anodes being greater than was expected, a good deal of cyanide would be used. He did not understand from the Paper that the process was actually at work. If it was, he should like to know whether the actual economy was greater by that method of precipitation than by the plain straightforward plan of displacing one metal by another, viz., by treating the solution of potassium cyanide containing gold, with zinc. There was a further point he should like to mention. The tailings of course became acid, on storage, by the oxidation of the iron pyrites which they contained. That acidity was fatal to proper cyanide extraction, because the weakest acid, as he had already indicated in the case of carbonic acid, acted upon the potassium cyanide, and caused it to be inoperative. The obstacle was circumvented by dosing the tailings with a certain amount of alkali. Lime and caustic soda (as mentioned by the Authors) suggested themselves as the most obvious means to that end. He did not find that any distinct opinion was given in the Paper as to whether lime or caustic soda was the preferable material, and should it be eventually found that the cheaper material, lime, was the better, one would naturally ask whether lime of sufficiently good quality could be obtained locally, or whether it had to be imported. There might be some practical advantage in using caustic soda as distinct from lime, but that point could only be determined by trial. His experience with South African limestones was that they were not of a quality to yield unexceptionable limes, but it might be that on the Rand they were more fortunately placed than was generally supposed; perhaps the Authors would be good enough to deal with that point more definitely.

Mr. D. A. Louis. Mr. D. A. Louis had had some experience in the treatment of slimy ores, but not on such a large scale as described in the Paper. One ore which he had experimented on was most difficult, the gangue being nearly all clay. It retained as much as 70 per cent. of its dry weight of water poured on it. With the object of facilitating its treatment he had mixed it with a certain quantity of sand to reduce its retaining power to 50 per cent. of its weight of water. He then mixed another quantity with about 80 per cent. of sand, and it retained only about 36 per cent. of water. He found that the quantity of material to treat under these circumstances was so much increased that the treatment could scarcely be considered

as suitable for adoption at a mine; but the leaching of the one that retained only 36 per cent. of water proceeded easily; with the one that retained 50 per cent. it went on slowly; and with the original material it did not succeed at all. He afterwards tried experiments with filter-presses, and found that they acted perfectly and extracted all the soluble constituents from the most tenacious clay, but they necessitated the subdivision into so many small masses that it seemed to him that the method would not answer in practice. He had then tried the process recommended in the Paper. He thought he would mix the material with the solvent, allow it to subside, and then decant off the supernatant solution, when he found the amount of liquid remaining behind with the clay was so large that it seemed almost impossible to extract a satisfactory amount of gold by that process. In the first decantation only a small amount of the whole solution was recovered. With the next solution there was still a large portion of the gold left behind, so that it seemed to him it would take not only too long, but would necessitate dealing with vast quantities of liquid. The next thing tried had been to agitate and suspend a filtering apparatus in the liquid. He had arranged to have a revolving brush working under the filtering apparatus and then applied suction to the latter. That answered considerably better than allowing the material to subside and then decanting, but it did not seem to work quickly enough. He finally tried suction beneath, providing an apparatus to sweep the surface of the filter; this served to keep the solution agitated, and at the same time prevented the surface of the filter from becoming clogged. With about 1 ton of material that answered well and worked quickly. In front of the leaching-vats he placed a series of wooden vessels, which were exhausted (only a small amount of pressure, about 5 lbs. per square inch, being necessary) and by turning a cock he connected a leaching-vessel with any one of these exhausted receptacles. The leaching proceeded quickly, and when the material became pasty he turned off the cock, filled up with water, keeping the agitating apparatus at work, and then repeated the process. Although that answered well with a small quantity of material, of course in the presence of such large amounts of material as had been mentioned in the Paper it might not do so. Those who had not had an opportunity of visiting the gold-fields would be naturally pleased with so graphic an account of the apparatus used as had been given, but he thought it was a pity that the Authors had restricted themselves to one system. Other systems were in use in South Africa, and it would have been satis-

Mr. D A. Louis.

Mr. D. A. Louis. factory to have had an equally good description of them. With reference to the remarks of Mr. Blount, he might mention that coagulation of clay was not necessarily accompanied by development of acidity. Then again, the zinc in solution did not pass away as a simple cyanide of zinc, but as a double cyanide, useless as a solvent for gold. One reason for requiring such a large quantity of cyanide of potassium, so much more than was required by the theoretical equation, was that the gold was not distributed evenly through the mass of material, but was distributed in a series of isolated particles, and enough potassium cyanide had to be supplied to reach every particle of material, whether it was gold or not, so that there might be sufficient cyanide to dissolve the gold wherever it happened to be.

Mr. Garland. Mr. JOSEPH GARLAND observed that the discussion had mainly dealt with the question of the treatment of slimes, which was natural enough, since the Authors had laid considerable emphasis on that point, and had said that there were vast quantities of slimes which could not be turned to account. It had been suggested that the best way to avoid the slimes difficulty was to produce no slimes. That would be an excellent solution of the problem if it were possible to carry it into effect. It was quite true that the stamp-mill produced a large amount of slimes, the ore remaining too long under the stampers and becoming pounded into a finer state than was necessary for liberating the gold. An ideal stamp-mill would, of course, be one which would discharge at once every particle small enough to pass through the screen, but that perfection had not yet been attained. Possibly improvements in that direction might yet be made, and that much-desired end might be approached if not fully reached. Seeing, however, that it was impossible to crush down any rock to a small size by any machine or any tool, without producing a good deal of fine powder, he confessed he was not sanguine that a machine would ever be devised, which would pulverize without producing fine powder or slimes, or that the ratio of slimes to sand would be materially reduced. If that were so, instead of fighting against the inevitable, the most rational plan would seem to be to endeavour to find an expeditious and economical method of treating the slimes. In the matter of treatment of slimes there seemed to be two important questions,—How to separate the slimes from the sands; and, How to extract the gold from the slimes; in other words, how to get the cyanide solution to percolate freely through them. With regard to the latter, it was interesting to learn from Mr. Frechville that

the Robinson Company had probably found a successful method of treating them, seeing that they were about to erect a plant to treat 8,000 tons of slimes per month. As to the question of separating the slimes from the sand, he was somewhat surprised to find no allusion in the Paper to the "spitz-kasten," or pointed-box method of separation. That apparatus had been referred to by Mr. Frechville, and was the best slime-separator which had come under his observation, and he should imagine that if the tailings could be passed direct from the copper plates into the spitz-kasten, the great difficulty of separating the slimes from the sands would be largely overcome. The distributor (Figs. 5, Plate 1), described as a conical hopper with radial pipes, was a very old and happy device, and was familiar to all who were acquainted with Cornish mines, where it was often used as an automatic feeder to the round buddle. Twenty-five years ago or more the Devon Great Consols mine had used that machine for sprinkling the copper-charged water which came from the mine over the scrap-iron which acted as a precipitant of the copper. The Authors were to be commended for applying to a nobler use an old and ingenious contrivance. Mr. Garland

Dr. Du Riche Preller referred to some remarks made in reference to the electrolytic process of precipitating gold as compared with the zinc process, to the effect that the electrolytic process was too complicated, and that the zinc process was much simpler and therefore preferable. That view was perfectly conceivable from the standpoint of the chemical manufacturer, because the zinc process involved large quantities and more or less concentrated solutions of cyanide of potassium, while precipitation by electrolysis required only very dilute solutions, and of course no zinc. On that ground alone he contended that the electrolytic process was not only simpler, but, both scientifically and commercially, the more economical process of the two. As to the alleged complexity of the electrolytic process, it might as well be said, and it was often said by the uninitiated, that gas, for lighting purposes, was much simpler than electricity, and therefore preferable. The manipulation of the thin plates and frames and the whole electrical apparatus of precipitation as depicted in Figs. 9, Plate 1, was as simple as an ordinary accumulator battery; and, electricity, in that as in all its other applications, was the acme of simplicity when it was properly handled. In that connection he well remembered having been much impressed with a remark of the late Sir William Siemens in that room, fifteen years ago, when Dr. Preller.

Dr. Preller. electricity as a practical science was in its infancy. In answer to a complaint that a dynamo erected at the Lizard lighthouse developed too much instead of too little energy, Sir William Siemens had replied that electrical machinery should be treated not as a mule, but as a racehorse.[1] Dr. Preller ventured to say that if so treated, the electrical apparatus for the precipitation of gold left nothing to be desired on the score of simplicity. With regard to the economy of the process, the saving of between 70 per cent. and 90 per cent. and even 95 per cent. of cyanide of potassium, and the fact that zinc shavings were entirely dispensed with, represented *per se* an important item of economy; while the cost of power, which also served other purposes, such as pumping, was negligible, and the amount of power used for the precipitation, viz., 4 HP. for 100 tons of solution, was extremely small. It was true that with the electrolytic process, a complete cycle of operations required one hundred and ten hours, as compared with ninety-six hours by the zinc process, or about twenty-four hours longer; but, on the other hand, the electrolytic process was much more searching, thorough and efficient, because the electric current, by introducing the factor of heat, intensified molecular rotation, and produced with an extremely weak solution a better result than the purely chemical process was able by forced action to obtain with a solution twenty times stronger. As in other metallurgical processes, notably in the deposition of copper and aluminium, so also in the precipitation of gold, electrolysis marked a striking advance upon the chemical process pure and simple. There were various gold-mining works in South Africa that were at present debarred by existing contracts from using the electrolytic process, but would introduce it as soon as those contracts for deposition by zinc expired; and if it were true, as had been recently stated, that the use of cyanide of potassium had saved £2,000,000 sterling in South Africa, he made bold to say that the electrolytic process, whether that of Siemens and Halske, or some improvement upon that, was destined to save a further equal sum. The absence of costs was noticeable in the Paper, and he would suggest that the Authors should add a statement of the comparative cost of installation and treatment, with particulars of the efficiency of the plant.

Mr. H. Louis. Mr. Henry Louis confined his observations to one or two engineering points of detail. The first was the statement in the Paper that an ideal site for a cyanide works was one having a fairly steep slope. Seeing that in South Africa the tailing sands,

[1] Minutes of Proceedings Inst. C.E., vol. lvii. p. 157.

as they left the vats, were not suitable for automatic conveyance, Mr. H. Loui
and seeing that there were no deep gullies into which the waste stuff could be run to be carried away by floods, it would seem, on the whole, that there was no great advantage in the steep slope alluded to. He would ask whether works laid out on a flat site would not offer advantages, from a mechanical point of view, at least as considerable as the slope. As the solution after leaving the precipitating-boxes had to be pumped back to the beginning of the operations, he thought that a more thorough circulation would be thus obtained. If the works were laid out on a steep slope there would be more water to lift than by working on a comparatively flat one. At the same time, he was aware of the advantages gained by running down the tailings and dumping them direct into the vats. Speaking only as to the handling of the solution, it seemed to him that a flatter site had distinct advantages, especially looking to the future of a process in which there would be a continuous cycle of operations. If there was a serious difficulty in pumping the solution from the end of the precipitating-boxes to the first solution-vat, it seemed rather to raise an obstacle; and there would be a greater disinclination to try the continuous process than if the works were laid out with a view to such continuous process. That process had been worked on a small scale in California; but he did not know that any details were available showing how it had been carried out, and what were the commercial results. Another feature in American practice, not possible in the Rand, was the getting rid of tailings by sluicing them out of the leaching-vat with a flush of water. He was not aware that that had been attempted in South Africa, and he should be glad to know if anything of the kind had been tried. He should also like to know whether the cyanide solution had any destructive effect upon the cement. It had been stated that, in the early days of the Rand, great objections had been raised to tanks lined with cement, on the ground that the cyanide solution had a disintegrating effect upon them.

Professor GEORGE FORBES observed that as the question of the Prof. Forbes
continuous process used in California had been raised, it was only right to mention the name of Dr. A. Scheidel, who was so well-known in connection with works in New Zealand, and had just issued a Report[1] to the State of California on the cyanide process as worked in Australia, New Zealand, and California. He did

[1] "The Cyanide Process, its Practical Application and Economical Results." California State Mining Bureau, Bulletin No. 5, Sacramento, 1894.

Prof. Forbes. not think that Dr. Scheidel's name should be omitted in such a discussion.

Mr. Smart. Mr. EDGAR SMART, in reply, said, with regard to Mr. Moreing's proposal to supersede crushing with stamps by "some other method," that the nature of the gold-bearing rock had greater influence upon the amount of slime produced than the method of crushing. The stamp-battery was in some respects a crude machine, and efforts were constantly being made to effect improvements upon it. It had hitherto, however, not been superseded, probably because its action was simple and efficient, and it could not get seriously out of order—all its working parts being easily visible, and all necessary repairs being within the power of even unskilled workmen. But the ordinary process was especially good when the cyanide treatment was to be carried out, as the previous removal of most of the coarse gold by amalgamation and concentration was an important advantage. The method of direct treatment of the tailings, attributed to Mr. Jennings, had been referred to in the Paper and its disadvantages had been pointed out. Although the results for this method were said to be superior to those obtained by the intermediate vats, no facts or figures had been given to support the opinion, except that oxidation of the contained pyrites might occur during removal, with resulting loss of cyanide, and that there was no labour required for filling. The latter was not quite accurate, as the pulp was distributed by a flexible hose in the hands of a Kaffir labourer. The amount of oxidation during transfer from the collecting- to the leaching-vats could only be slight, and it was known that tailings so removed were quite neutral and required practically no lime; moreover, it must be remembered that oxidised pyrites allowed of a better extraction. There must further be more oxygen mixed with the tailings tipped from trucks than in tailings deposited directly by water, and oxygen was certainly necessary for quick and efficient treatment. The cost of transfer was about 3*d*. per ton, and was therefore more than compensated for by an increase in the extraction of 2 grains per ton.

In reply to Mr. Vautin, the cocoa-matting filters were generally attached to the sides of the vats by 1-inch clout-nails, spaced about 3 inches apart, but they were sometimes held in place by curved wooden strips nailed round the vat. The joint for staves described by Mr. Mactear was certainly an excellent one, and was, he believed, generally unknown on the Rand. He quite agreed as to the disadvantages of using excavations lined with brick and cement for leaching vats.

Mr. Smart.

The chief objection to the electrical precipitation process had been the alleged complication on account of the large number of iron anodes and lead kathodes required. It would be almost as reasonable to object to the zinc process on account of the large number of individual zinc shavings required, the object being in both cases to obtain a large area of active surface. As had been stated in the Paper, the sheets of thin lead-foil were fixed in light wooden frames, and had only to be removed singly when sufficient gold had been deposited upon each one. A new foil was inserted in the frame which was replaced in the box, while the old foil with the gold upon it was placed in the safe until enough had accumulated for cupellation. The iron sheets did not require to be moved and therefore gave no trouble. It was clear, then, that the working of the process was quite as simple as with zinc boxes, which had to be replenished with fresh zinc from time to time as it dissolved. The cleaning-up of the gold won by electricity was conducted in the following stages: 1. Occasional removal of the lead-foil without interference with the operations. 2. Cupelling the lead bullion. 3. Smelting into bars of very fine gold. 4. Reduction and recovery of the lead. With zinc precipitation, the clean-up of the gold required the same number of operations, which were at least as troublesome, viz.: 1. Washing out the precipitated gold from the zinc shavings with considerable disturbance of routine once or twice a month. 2. Settling precipitated gold and scraping it up in the form of mud. 3. Roasting the mud to oxidise the zinc mixed in it with the gold. 4. Smelting into bars of about 750 fine. Of course no zinc was commercially recoverable. The two advantages which had obtained for the electrical process its present strong position were:—1st. That it allowed of the use of weak solutions and thereby effected a great economy in cyanide; and 2nd. That by burning coal in a boiler instead of zinc in a cell or precipitation-box the same economy was effected which had made electric lighting and other applications of electricity commercially successful. Consequently electricity had given in actual working 1*s.* 6*d.* per ton more profit than the zinc process worked under similar conditions by the same company. It was in use at the Metropolitan and the Worcester Cyanide Works, and was being introduced into those of the May Consolidated and the New Crœsus Companies.

The slime plant to be erected by the Robinson Gold Mining Company had been referred to as evidence that a successful method for treating slimes had been evolved. The slimes at the Robinson Works were to be treated, and the plant was built,

Mr. Smart. by the Rand Central Ore Reduction Company, under the supervision of Mr. Charles Butters, and electrical precipitation was to be used. The cost of complete plants varied, of course, with the size, the distance to which material had to be conveyed and the facilities for erection; but in and around Johannesburg it might be roughly stated at £2 for small and £1 for large works per ton treated per month. Thus a 3,000-ton plant would cost about £6,000, and a 15,000-ton plant, say, £16,000. Electrical precipitation added between 10 per cent. and 20 per cent. to the first cost.

At most places on the Rand where concentration had been successful, the Frue-Vanner system was employed. One or two companies had used the Scoular shaking-table with success. In this table the direction of vibration made an angle of about 45° with the direction of flow of the pulp. Buddles with revolving arms after Australian patterns had been tried, but had in most cases been abandoned. At the George Goch Company's works, excellent concentrates had been produced by passing the battery-pulp from the plates over simple rubber "blankets" with longitudinal corrugations. Almost any apparatus would separate the heavy particles of pyrites, say from 3 per cent. to 5 per cent. of the Rand ores; but after that had been done, no apparatus had been produced that would concentrate the remaining gold from the tailings in a satisfactory manner. In removing the heavy pyrites from the sand, the concentrators took only about 2 dwt. per ton from say 6-dwt. tailings. Consequently if 100 tons were concentrated down to 5 tons the resulting materials would be 2-oz. concentrates and 4-dwt. tailings; and it was the latter material, constituting about 95 per cent. of Rand ore, which was treated usually by cyanide. In fact, it seemed to be a general rule that tailings specially amenable to cyanide treatment were most unsuitable for concentration, and *vice versâ*. The reason for this was not difficult to understand, for it was easy to concentrate when the gold was itself in coarse particles or was associated with heavy matter such as coarse pyrites; and in this case naturally any method of extraction by dissolving the gold was at a disadvantage. On the other hand, where the gold was very fine and evenly distributed throughout the mass of the material, it was readily dissolved; but the difficulties of concentration were then great, because fine particles of gold were mixed with grains of sand which were relatively much larger. By ordinary hydraulic concentration or classification it seemed that there would always be the insuperable difficulty, that a small particle of heavy

material would behave almost exactly as a larger particle of lighter material. If so, it was evident that hydraulic classification, as it was sometimes termed, as, for instance, the use of spitz-kasten, could be of assistance towards subsequent concentration; for the classifier was really a concentrator, and its action was to separate the material into groups such that the hydraulic behaviour of all the particles in any one group was about equal. Consequently, these particles were less liable to separation by any machine acting upon the same principle as the one which grouped them. If, however, a first classification could be made entirely by screens, and depending solely upon the size of the particles and not upon their specific gravity, subsequent concentration would be greatly assisted, because each concentrating-machine, having only one size to deal with, could then give full effect to the differences of specific gravity. Mr. Smart.

For the hooping of the larger vats it would be impossible to use all 1-inch bars; because near the bottom there would not be space enough for the number required. The objection to welds disappeared in the case of a 40-foot vat of 127 feet in diameter. To avoid welds, each hoop would have to be made in eight sections instead of four, as at present; and consequently the number of castings, nuts, screwings, and labour, would be too great. Continuous castings for the hoop-joints would be distinctly disadvantageous, because the stave nearest to the casting was not so well supported as the rest. By placing the castings step-wise this occurred at one hoop in each stave, whereas continuous castings would leave the staves on either side of them without proper support throughout their length. The hoops were, of course, spaced according to the pressures at each part, and were much closer at the bottom. Chains used as separate hoops would be slightly better than bars, but more expensive, and wire rope wanted a satisfactory method of joining the ends. A continuous chain or rope for the whole vat was out of the question, because a failure at any one place would involve the rebuilding of the vat, with much loss of gold.

In reply to Mr. Blount, the slimes were certainly distinguishable by their argillaceous nature, although they contained a large amount of very finely-crushed quartz; and it was in some cases difficult to draw a line between the finest of the sand and the most siliceous portion of the slimes as deposited in the dams. The object of collecting-vats was not to store slimes for future use, but to collect them for immediate treatment with the sand

Mr. Smart. the largest amount of slimes possible without them rendering the material unleachable. No trouble had occurred on account of the accumulation of zinc cyanide in the solutions, but he could not agree that the double cyanide of zinc and potassium might be an efficient extractor of gold. The fact that zinc displaced gold in the precipitation-box showed that gold could not displace zinc in the leaching-vat. The reason for the actual consumption of cyanide being so much greater than the amount theoretically equivalent to the gold dissolved (being roughly about ¼ lb. per dwt. of gold) accounted for, was that substances were present in the tailings which combined with cyanide and decomposed it, such as acid salts, organic matter, &c.

The use of an excess of air and oxidising agents had been largely experimented upon, the Rand chemists being quite aware of the value of oxygen in chemical reactions. Attention had, he believed, first been directed to the matter by Mr. H. F. Julian. In general the amount of air mixed with the tailings seemed to be sufficient in practice to supply the necessary oxygen, except perhaps, as already mentioned, in the case of direct filling with water. He could not agree that works should be laid out preferably on a flat site, because such an arrangement did not facilitate the handling of solutions; and in any case the transport of material was a much more important item in the cost of treatment, and therefore in the design of works.

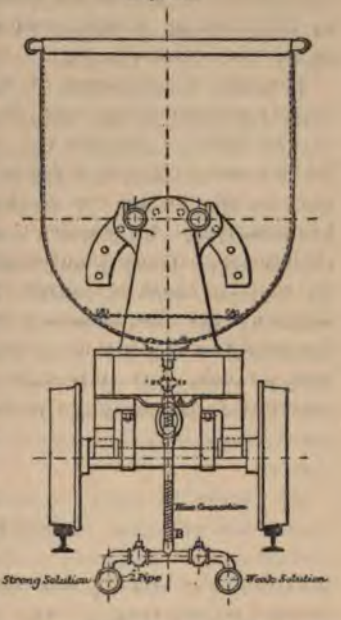
Correspondence.

Mr. Appleby. Mr. C. J. Appleby had long thought that methods could be devised for treating tailings by the cyanide process, which would overcome some of the difficulties referred to by the Authors, and make it available under any circumstances where, as usually carried out, it could not be profitably employed; and he was glad to be able to direct attention to such a system. The experience of Mr. L. F. Gowans, of Johannesburg, in gold quartz reduction-works had clearly indicated the necessity for some system applicable to large or small quantities of tailings which were, at present, only refuse, but which would amply repay the cost of treatment by the cyanide process, if the appliances were less costly and more portable than the vat system which the Authors had described, and if it also admitted of the

impervious layers of slimes, almost always present, being easily manipulated. Those objects had been attained by the use of one or other of the systems devised by Mr. Gowans, in conjunction with Mr. P. V. Appleby, which might be described as the truck system and the cylinder system. Mr. Appleby.

The truck system was adapted for taking the pulp as it left the amalgamating-tables or the concentrators. In that condition the collection of slimes was rarely sufficient to interfere with the action of the cyanide, but if it should do so, the mass was easily disturbed, and complete penetration was produced. The trucks, *Fig. 11*, as usually made were of steel, and carried about one cubic yard, being arranged to tip on either side, or either end as required. Each truck was provided with a filter at the bottom, which was easily taken out for cleaning or renewal. A short length of flexible pipe with a bayonet-joint connected the nozzle from the filter with the solution-pipes, which conveyed the leached products to the precipitating-tanks whence the bullion was extracted in the usual manner, the treatment being that usually adopted, as described by the Authors. The absence of manipulation from the time the trucks had been charged by bucket-elevator, or otherwise, until the leaching had been completed and the spent tailings had been run to the dump, recommended the system for use under many conditions where no other could be profitably employed. In most cases it was obviously desirable to construct a siding which would take the number of trucks requisite for leaching the maximum quantity of tailings to be treated in a given time. Each truck might be expected to deal with between 3 tons and 4 tons of tailings in a day of ten to twelve hours.

Fig. 11.



The cylinder system was adapted for treating tailings which had lain for some time and were largely intermixed with impervious

Mr. Appleby. slimes. The cylinder was built of steel, and was supported by end-bearings eccentrically to the axis. The capacity of the cylinder was about 6 tons, and it had a closely-fitting hinged door at the charging end and a removable filter at the other end. A simple arrangement of gear admitted of the cylinder being rotated from time to time for the purpose of breaking up the slimes and so accelerating the leaching process. When that had been completed and the filtered solution was drawn off, the cylinder was turned until the hinged door was at the lowest point. That being opened the leached tailings were instantly discharged into a truck or shoot to be conveyed to the dump. The cylinder was then ready for a fresh charge.

It would be seen that, by both systems, the process was practically continuous, and might be carried out with a minimum cost for labour; also that the cost of plant was much lower than that for the vat system, and especially so if the levels were unfavourable to the latter. A further improvement was now occupying his attention. That was a mechanical arrangement by which the slimes were treated automatically, without any handling, and he believed such a system would gradually supersede all the present plant. If the recent discovery of a reagent, for quickening considerably the action of the cyanide, proved on a commercial scale as successful as it had been in the laboratory, there would manifestly be an additional incentive to the employment of automatic mechanical means for treating tailings by the cyanide process.

Mr. Smart. Mr. SMART, in reply, remarked that the system of leaching in trucks was not new, having been already practised in Europe on a small scale. The only saving which the plan would effect was the tipping of the material into the vats and its subsequent discharge into the trucks. The cost of haulage would be the same in both systems; but in that proposed by Mr. Appleby the wages-bill for changing the numerous connections between the trucks and the precipitating-boxes would be large. Leaching from tanks required about seventy-two hours, so that it was not safe practice to deal with 3 tons or 4 tons in twelve hours in each truck, only three or four hours being thus allowed for the treatment of a charge. Assuming that 1 ton could be treated in a truck in twenty-four hours, an establishment to give an output of 600 tons per day would require six hundred trucks, the cost of which would form an excessive capital charge. The system would also involve the superintendence of six hundred instead of, as at present, only

five separate leaching-vessels. He had tried the method of treatment in cylinders upon a plant dealing with 24 tons per day, and had concluded that no economy could be effected by its use. He considered that attempts to treat impervious slimes with sand in a rotating cylinder were unlikely to prove successful. Mr. Smart.

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26 February, 1895.

SIR BENJAMIN BAKER, K.C.M.G., Vice-President, in the Chair.

The discussion upon the Paper on "Plant for the Extraction of Gold by the Cyanide Process," by Messrs. C. Butters and E. Smart, occupied the evening.

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5 March, 1895.

SIR BENJAMIN BAKER, K.C.M.G., Vice-President, in the Chair.

The Chairman alluded to the recent death of Mr. Alfred Giles, Past-President, which had occurred on the anniversary of his election as a Member forty-nine years previously, and read the following resolution which the Council had passed, and which was adopted by the members present:—

"That the Council desires to place on record its sincere sympathy with the widow and family in this bereavement, and to assure them of the high esteem entertained for Mr. Giles, alike for his professional attainments and for his personal qualities, which led to his being elected a member of the governing body in 1878, and the President for the Session 1893–94, an office he filled with credit to himself and with advantage to the Institution."

It was announced that the several Associate Members hereunder mentioned had been transferred to the class of

Member.

WILLIAM COLLINGWOOD.
THOMAS BENJAMIN GRIERSON.
EDWARD ARTHUR HOARE.
WILLIAM OWEN LUCAS.
JOHN POLLARD.
HENRY JOHN TINGLE.
MAURICE FITZ-GERALD WILSON.

And that the following Candidates had been admitted as

Students.

HAROLD WOOD BARKER.
ERNEST EUSTACE BENHAM.
EDWIN ELLIOTT BROMAGE.
ARCHIBALD PRESTON CAMERON, B.A.
GEORGE ROBERT GRAHAM CONWAY.
WALTER DAMAREL COODE.
JOHN DUNCAN CAMPBELL COUPER.
PERCY JOHN COWAN.
CECIL STANHOPE DAVID, B.A.
WILLIAM FRANCIS FOX.
ROBERT HALLEY GARVIE, B.Sc.
FREDERICK HARRY GREENHOUGH.
JOHN POTTER HALLAWAY.
ROBERT FARRAN HANNA.

Students—continued.

CHARLES HOGAN.
CHARLES JOHN HOWE.
ERNEST EDWARD HUTCHINS.
GEORGE KEYTE.
MAXIMILIAN ROBERT LAWRENCE.
RICHARD PRIESTLEY LAWRENCE.
HENRY GARDINER LLOYD.
ATHERTON GREVILLE EWING MATHESON.
PERCY ALBERT HIRST MIDDLETON.
JOHN FREDERICK NIELSON.
RALPH OAKDEN.
GEORGE JOHN PRICE, B.A.
CHRISTER PETER SANDBERG, Jun.
DONALD GRAFTON SIMPSON.
ARTHUR GODFREY STAVELEY.
HUBERT ROBERT THOMAS, B.Sc.
CHARLES BARNARD WIGG.
CARLOS VAN ZELLER.

The Candidates balloted for and duly elected were: as

Members.

ALEXANDER CROMBIE HUMPHREYS.
BASIL MOTT, A.R.S.M.
FRANK JULIAN SPRAGUE.
ARCHIBALD WILLIAM WILLET.

Associate Members.

GEORGE BALL.
FRANK CARTWRIGHT, Stud. Inst. C.E.
FREDERICK ALBERT COLEMAN.
NORMAN BONNINGTON DICKSON.
EDWARD WILSON DIXON.
GEORGE MASON HALDEN.
JOHN HESKETH.
ARTHUR FAYRER HOSKEN, Stud. Inst. C.E.
CHARLES JAMES JENKIN.
THOMAS HENRY KIRKPATRICK.
FRANCIS SAMUEL L'ESTRANGE, Stud. Inst. C.E.
RAJESVARA MITRA, B.A., *Rai Sahib.*
RICHARD WILKINSON NASH.
HORACE FIELD PARSHALL.
ALEXANDRE SCHEID.
JOHN FRANCIS CLEVERTON SNELL, Stud. Inst. C.E.
CHARLES CONSTANT VERNET.
ARTHUR LEWIS WEBB, F.C.H.
ERNEST MOORE WILSON.
FREDERICK AUGUSTUS YERBURY.
HENRY YORK.

(*Paper No. 2837.*)

"Electrical Haulage at Earnock Colliery."

By ROBERT ROBERTSON, B.Sc., M. Inst. C.E.

THE plant described in this Paper was installed at Earnock Colliery for the haulage of coal-hutches in parts of the mine, near to the working-faces, where horses had hitherto been used for that purpose. The transmission of the power generated at the surface, and its use in electrical hauling-engines in the workings, will be more clearly understood after a brief description has been given of the colliery itself, and of those of its seams into which these hauling-engines have been introduced. The colliery is situated in a coal-field extending to about 1,000 acres, near Hamilton, in Lanarkshire, and has been in operation for about fifteen years. Five seams are being worked, and in all the

haulage has hitherto been accomplished by steam hauling-engines, horses and self-acting inclines. The seams into which electrical hauling-engines have been introduced to replace the horses are:—

Coal-seam.	Average Thickness.	Depth from Surface.
	Feet. Inches.	Fathoms.
Ell	6 9	120
Pyotshaw.	4 3	129
Main	4 2	131

These seams are worked from two shafts, of which No. 1 is used for winding, and No. 2 for lowering and raising the workmen, and timber and other materials. No. 1 shaft measures 22 feet by 7 feet in cross-section, and is sunk to the Ell seam, at a depth of 120 fathoms, the coal from the Pyotshaw and the Main seams being brought to this level by cross-measure mines. The cage at No. 1 shaft can carry four hutches with 12 cwt. in each, and, for a day of ten hours' working, the output amounts to about 1,200 tons. No. 2 shaft, 21 feet by 8 feet in cross-section, is situated 35 yards west from No. 1, and is sunk to the Ell seam also. The stoop-and-room system is followed for working the Ell seam, while the Main and Pyotshaw seams are worked on the long-wall or stoop-and-room system, according to the local conditions of the coal or roof.

Fig. 1, Plate 2, shows in outline the main haulage-roads in the Ell and Main seams. The roads in the Ell seam are indicated by hard-drawn lines, and those in the Main, 11 fathoms below it, by dotted lines. The following Table gives the lengths and gradients of the different portions of these roads:—

Road.	Length.	Average Gradient.	With or Against the Load.	Road.	Length.	Average Gradient.	With or Against the Load.
	Yards.				Yards.		
A B	130	1 in 18	With	J L	415	1 in 25	Against
B C	560	1 „ 18	With	M N	70	1 „ 30	With
C D	235	1 „ 12	Against	N O	170	1 „ 12	Against
D E	300	1 „ 20	With	O P	75	Level	
E F	120	1 „ 20	„	P Q	275	Level	
F G	155	1 „ 20	„	Q R	40	1 in 20	With
G H	220	Level		R S	230	1 „ 20	„
F J	265	1 in 30	Against	R T	545	1 „ 30	„
J K	265	1 „ 30	„				

The steam hauling-engine for the Ell seam is placed at B,

Fig. 1, about 130 yards from the bottom of No. 1 shaft, and consists of two horizontal cylinders, 20 inches in diameter and 48 inches long, driving six flanged drums, 6 feet in diameter and 18 inches broad, fitted with brakes, &c. This engine works three roads on the main- and tail-rope system, having two separate drums and ropes for each road. The principal road, between the shaft and the point marked F in the Fig., is about 1,200 yards long. The other two roads branch off to the right 50 yards beyond B, and are respectively 350 yards and 770 yards in length. These three roads may be worked simultaneously by this engine, as each pair of drums has an indicator attached to show the position of the train on the road, enabling the man in charge of the engine to obviate risk of collision at any of the junctions of the roads. The coal is brought from the points H, K, and L to the point F on the principal road by an electric hauling-engine in place of horses. The steam hauling-engine, which is used in the Main coal-seam, is placed about 30 yards from the point M, Fig. 1. This engine consists of two horizontal cylinders, 12 inches in diameter and 24 inches long, and drives an endless rope by means of a Thornecliffe wheel. This endless rope passes down the cross-measure drift from N to O, which crosses and taps the Pyotshaw coal-seam. It then passes along the road PQ to a point about 200 yards beyond that marked Q. The coal is brought to this road from the points marked S and T, by an electric hauling-engine. The two electric hauling-engines drive endless ropes running upon rollers between the rails.

Generating Plant.—The house containing the generating plant is situated near the pit-head, and is shown in plan in Fig. 2. The dynamo, No. 1, for generating the power for the hauling-engines gives an output of 100 amperes at about 490 volts when running at a speed of 620 revolutions per minute. It is compound-wound, the resistance of the armature being 0·145 ohm, and that of the series and shunt field-magnet coils 0·082 and 236 ohms respectively. This dynamo is driven by a belt from a shaft coupled direct to two Westinghouse engines, one at each end. These engines are single-acting, with vertical cylinders 13½ inches in diameter and 12 inches stroke, and are driven at 350 revolutions per minute, developing together, with 50 lbs. per square inch steam pressure, 122 HP. They may be connected to or disconnected from the shaft without stopping, by means of sliding couplings operated by hand-levers. Two smaller dynamos for lighting purposes, giving an output of 12 kilowatts and 5 kilowatts respectively, are driven from the same shaft.

Conductors.—The conductors, between the generating plant at the surface and the hauling-engines in the workings, are carried down No. 2 shaft in iron pipes, and along the roads underground upon insulators attached to the roof or to the side-timbering. Throughout the whole installation completely metallic and insulated circuits are used. Those of the conductors, which are encased in pipes, are insulated with vulcanized india-rubber, braiding and compound, and those carried upon insulators underground with pure india-rubber, braiding and compound. Between the power dynamo and the bottom of No. 2 shaft, they consist of nineteen No. 14 S. W. G. copper wires, of 0·0973 square inch total cross-sectional area. At the bottom of this shaft they divide, one cable, consisting of nineteen No. 16 S. W. G. copper wires, of 0·0624 square inch total cross-sectional area, passing to the hauling-engine at E, Fig. 1, the other, consisting of seven No. 15 S. W. G. copper wires, of 0·0289 square inch total cross-sectional area, to that near the point R.

Electrical Hauling-Engines.—There are two electrical hauling-engines, one of which is placed in the Ell, and the other in the Main coal-seam. The hauling-engine in the Ell seam, at E, Fig. 1, is capable of a maximum output of 35 HP. when running at 770 revolutions per minute, and taking 76 amperes at about 400 volts. The motor is shunt-wound, the resistance of the armature being 0·107 ohm and that of the field-magnet coil 202 ohms. The hauling-engine is started and stopped by a switch, and, in order to effect these operations slowly and also to provide for a temporary regulation of the speed when required, a series of resistances, operated by the switch handles, is provided. The arrangement of this electrical hauling-engine is shown in Figs. 4, Plate 2. The motor drives an intermediate shaft, which in turn drives a shaft carrying two clip-pulleys with Hurd clips. Each pulley is provided with a friction-clutch and brake, and the levers for working these are operated by hand-wheels, arranged conveniently for the man in charge. The gearing is arranged to drive the ropes at a speed of about 3 miles an hour. The electrical hauling-engine situated in the Main seam near the point marked R, Fig. 1, is of only 12 brake horse-power, and has but one clip-pulley; in other respects, however, it is similar to that in the Ell seam. Although there is practically no danger from gas in the localities where the hauling-engines are placed, it was considered more satisfactory to adopt the precaution of covering the motors and switches with gas-tight casing.

Haulage Cables.—The hauling-engine in the Ell seam operates

two ropes, the arrangement of which, together with enlarged plans at the points E, F and J, is shown in Fig. 3. The first rope, after passing over a balance-wheel in a recess opposite the hauling-engine, travels round the following circuit: E, F, J, L, J, K, F, and back to E, Fig. 1, a total length of 2,160 yards; the second, after passing over the balance-wheel, travels round the circuit E, F, G, H, and back to E, a total length of 1,020 yards. These endless ropes consist of steel-wire cable $\frac{3}{4}$-inch in diameter, and are carried upon small rollers between the rails, 9 inches broad and $4\frac{1}{2}$ inches in diameter, placed at intervals of about 30 feet. At all corners and at the end of each branch the rope is taken underground and round horizontal grooved-wheels 5 feet in diameter. These wheels are mounted upon a centre-pin cast on to a foot-plate, and are slid into position from the top and held by a washer and split-pin. The spaces containing these wheels are covered by planks, upon which the rails are laid in such a way that the wheels are accessible for repairs and oiling, and can be easily removed and replaced. At the corners where the ropes go underground and the natural gradient is against the direction of motion of the rope, one road is carried up on an embankment with a gradient of 1 in 8 to a sufficient height to allow, say, 30 yards of falling gradient of about 1 in 30, to carry the trains of hutches round the corners without the aid of the rope. A complete system of communication with the hauling-engine house is established by electric bells throughout these roads, whereby the man in charge can, by arranged signals, be warned from any point of the route to stop or start either of the ropes. It will be seen from the Table of lengths and gradients of these roads given on p. 48, that for the greater part of its length the gradient of the longer road is against the load, whereas in the road served by the short rope the gradient is entirely with the load. The rope driven by the hauling-engine in the Main seam, after passing round a balance-wheel in a recess opposite the hauling-engine, travels to S, returns to R, passes on to T, and back to the hauling-engine, and has a total length of 1,580 yards. Throughout this road the gradient is with the load.

Working.—In order to explain the work of the electrical hauling-engine in the Ell seam, it is necessary to describe the steam main- and tail-rope system of haulage used on the road between the point F, Fig. 1, and the pit-bottom. As already stated, this is operated by one pair of drums attached to the steam hauling-engines at B. It will be observed from the Table that from E to D and from C to B the gradient is with the load, while

from D to C the gradient is against the load. Two sidings are arranged between the points E and F, one for marshalling loaded trains to be taken to the pit-bottom, and the other for the empty hutches to be distributed to the different points, H, K, or L. The portion of the road from E to D is worked by a service-rope, which is detached when the train arrives at D. The hutches are drawn along this road in trains of about thirty-six hutches in each, and as many as twenty-one trains can be taken from the point F to the pit-bottom in one shift of ten hours, giving an output of over 400 tons in one shift. This quantity of coal must be gathered from the points K, L and H, and one or two intermediate points to which the hutches can be conveniently brought from the working-faces by means of self-acting inclines or otherwise, and this output of over 400 tons can easily be maintained by the electrical system. The number of men employed on each shift is as follows: One man in the hauling-engine room, five clip-men or chain-runners on the section between the junction at F and the points K and L, and one on the section between F and H, with one roadsman travelling upon both sections. The hutches are attached to the endless rope by a Smallman clip, in trains of six at a time, and as many as four loaded trains are sometimes drawn by rope simultaneously. The ropes driven by the electrical hauling-engine and communicating between the siding at E and the points L, K, and H, run continuously, and the trains are attached and detached from them while they are in motion without difficulty. Each hutch weighs about 5 cwt. when light, and carries on an average 12 cwt. of coal, giving an average gross weight of 17 cwt. per hutch. The hauling-engine was originally intended for an output of 250 tons only in ten hours from these two sections, but by slightly reducing the speed of the ropes, and accordingly increasing the hauling-power, the output, as already explained, has been increased to over 400 tons in ten hours. About 60 tons of this load come from the direction of the point H, so that the remaining 340 tons are taken from the other lines, the gradients of which are heavy and against the load. To give the same output from this section by horse-haulage it would require between thirty and forty horses, and each horse would need a man in attendance. It would, however, be impossible to employ so great a number of horses in the limited space without confusion. Formerly in this section, when the distance from the working-faces was less, and before the installation of electrical-haulage, about ten horses were employed to work the roads now served by the wire rope; the output was then about 180 tons per day, but now the output

in the same time is 400 tons, and all the horses are dispensed with.

The hauling-engine in the Main seam is not yet working to its full capacity, so that the work it is doing will not be detailed. The output now is between 150 tons and 200 tons in ten hours.

From the results of working during about eighteen months since the installation was completed, the following is a close approximation to the saving which has been effected. Taking the present output by the two electrical hauling-engines at 600 tons in ten hours it is estimated that, even if the same work could have been done by horses, it would have required forty horses and forty men (in addition to those at present bringing the coal from the working-faces) to do the same amount of work. The horses of the class employed cost about £30 per head. Renewal and depreciation at the rate of 15 per cent. per annum gives an annual charge of £180. The cost of feeding, &c., is about £30 per annum per horse. The wages paid to the horse-drivers is about 5*s.* 6*d.* per day. The annual cost of working with forty horses is, therefore:—

	£.
Depreciation and renewal of forty horses, 15 per cent. of £1,200	180
Keep of horses, forty at £30 per annum	1,200
Wages of forty men at 5*s.* 6*d.* per day for, say, 250 days	2,750
Total	£4,130

The annual cost of working and maintaining the electrical installation is:—

	£.
One electrical engineer at 10*s.* per day for 250 days	125
Twelve men at 6*s.* per day for 250 days	900
Coals, oil, stores, &c.	500
Upkeep and depreciation:—	
Building, say, 5 per cent. on £600	30
Machinery, pulleys, ropes, &c., 15 per cent. on £2,900.	435
	£1,990

Deducting the cost of working and upkeep of the electric haulage plant from the estimated cost of doing similar work by horses shows the substantial saving of £2,140 per annum to be effected by the electrical installation.

The steam is obtained from the existing boilers at the colliery, and no appreciable difference has been observed in the consumption of coal since the new machinery was started; but in making such a comparison as the above, the probable cost for coal should

be assumed as if the steam were supplied from a separate boiler. From experiments to test the efficiency of the plant, the following information was obtained:—The loss in the engines is about 16 HP.; in the shafting about 0·45 HP.; in belt and dynamo friction, 3·4 HP.; and in exciting the dynamo, 2·2 HP. These losses, approximately constant for all loads, amount to about 22 HP., and constitute the engine-room losses. The loss in the engine is large on account of the available steam-pressure being low—only 50 lbs. per square inch.

Pumping.—Although there was no intention to include pumping in the installation, a small burst of water between the points J and K, Fig. 1, occurred shortly after the plant was started, and a small pump was erected and worked by the haulage rope. The pump has pistons 3 inches in diameter with a length of stroke of 6 inches, and is double-acting. It is driven by a grooved pulley 20 inches in diameter, over which the wire-rope is led, and the necessary amount of friction is obtained by a jockey-pulley and lever. The height to which the water is raised is only about 20 feet, when it is taken up by a larger pump.

Cost.—The total cost of the installation, including all machinery, pulleys, wheels, wire-ropes, houses, &c., has been approximately £3,500. The entire plant has been supplied by Messrs. W. T. Goolden & Co., Messrs. Strain, Robertson and Thomson, of which firm the Author is a member, being the Engineers.

The Paper is accompanied by five sheets of tracings from which Plate 2 has been prepared.

(*Paper No. 2814.*)

"Water-Power applied by Electricity to Gold-Dredging."

By Robert Hay, M. Inst. C.E.

In many mining districts there are deposits of gold which cannot be worked owing to the difficulties of transport and the dearth of fuel. The application of water-power transmitted to a distance by electricity is, therefore, a subject which may well command attention in well-watered countries like New Zealand, where a plentiful supply of power is obtainable; for intervening hills and valleys form no obstacle to its transmission, there being few districts through which light wires and poles cannot be easily carried.

The plant described in this Paper is the first of its kind constructed in New Zealand. It was designed by the Author for gold-dredging on the River Shotover, at a point about 30 miles from its confluence with the Kawarau River and 25 miles from Queenstown, a small town situated on Lake Wakatipu, which lies about 1,000 feet above sea-level. The Shotover runs through rugged and inhospitable country, generally in precipitous rocky gorges, and is only accessible by tracks cut down the leading spurs and gullies. Since the dredge commenced operations, however, a mountain road has been constructed at a considerable elevation above the river, and extends some 20 miles towards the Upper Shotover dredging-ground, opening up to some extent the interior of that part of the country.

All the bucket- grab-, and suction-dredges hitherto employed in New Zealand have been actuated by steam-power; bituminous coal, lignite or fire-wood usually being fairly plentiful, and accordingly moderate in cost. In the case referred to, however, fuel could only be obtained at prohibitive prices, as it would have been necessary to transport it to the dredge for long distances over the mountain tracks on the backs of horses. Water-power in a convenient form was found to be available at a branch creek, but for many reasons it could not be applied directly to dredging. It was therefore decided to transmit the water-power

by electricity to the dredge in whatever part of the river it might be working.

The water was obtained from a creek 1½ mile distant, and was brought, by a race cut in the side of the hill, or, through places where the ground was too precipitous or loose to carry the race, by a timber flume, to a pressure-tank situated at a point 524 feet above the generator-house. The race is 2 feet 6 inches deep, and 3 feet wide at the bottom, and the sides are cut with slopes of 2 in 1. The flume is rectangular in cross-section, 2 feet deep and 3 feet wide, and, in places where it could not be wholly set in a cutting along the side of the hill, is carried partly upon trestles standing about 6 feet apart. The pressure-tank is 20 feet long and 12 feet wide at the bottom, and has sides with slopes of 1 in 1 and 2 in 1. The water passes from the pressure-tank through a bell-mouth covered by a wrought-iron grid and is carried in steel pipes to the generator-house.

The pipes are of rolled steel of 16 and 11 B.W.G. with double-riveted longitudinal seams and single-riveted circular seams with 1½-inch lap. The pipes are each 19 feet 6 inches long over all, and are jointed with wrought angle-iron flanges riveted to the pipes. The internal diameter of the main pipe is $14\frac{3}{16}$ inches.

The quantity of water available in ordinary seasons is 240 cubic feet per minute; but in dry weather after a fine winter, when the snowfall has been light, the supply falls to about half that quantity. This, however, is sufficient to develop the necessary power.

The generator-house is situated about midway between the ends of the portion of the river to be worked, which is about 4 miles long. The prime-mover at the generator-house is a 4-foot Pelton water-wheel, on the buckets of which the water impinges from a 1½-inch nozzle at a pressure, in the pipes outside the station, of 228 lbs. per square inch. The Pelton wheel drives by belts two Brush-Victoria series-wound dynamos which, when working at their normal speed of 700 revolutions per minute, give each an electromotive-force of 650 volts and a current of 40 amperes, or together a total electrical output of nearly 70 HP. The two dynamos are coupled in series. A Buss-Sombart tachometer, driven from the armature shaft of one of the dynamos, indicates their speed, while a Soames-Nalder ampere-meter and a Cardew volt-meter (the latter reading up to 1,400 volts) indicate the current and electromotive-force respectively. The Pelton wheel has no automatic regulator, as the work required of it is fairly constant. It was necessary,

however, to provide against the possibility of an abnormal increase of current, due either to accidental short-circuiting of the line wires or to the sudden arrest of one of the motors, which might result in damage to the generator armatures; and to provide also against racing of the Pelton wheel and dynamo, which would take place if the circuit was broken or the load suddenly thrown off one of the motors by a belt leaving the pulley. This has been accomplished in the following manner. Two electro-magnetic switches are placed in circuit with the dynamos and motors, and are so adjusted that in the event of the current increasing to 3 amperes above its normal amount, one of them, and in the event of it decreasing to 3 amperes below it the other one, disconnects the line and motors from the circuit and throws into it in their place a set of iron-wire resistance-coils constituting an artificial load of the normal amount. If anything occurs to the line or motors to cause an abnormal increase or decrease of current, the dynamos are therefore automatically protected and continue to work as if nothing unusual had occurred. When either of the switches comes into action, an electric bell calls the attention of the attendant. The contrivance has been found to answer well in practice, and has on several occasions saved the dynamos from the risk of damage.

The conductors between the station and the dredge form a completely metallic circuit, and consist of bare copper wire of No. 4 S.W.G. supported upon Johnson-Phillip fluid insulators. The supports are old 40-lb. rails with a short hard-wood cross-arm bolted to each about 2 feet from the top; this arm carries the insulators for the conductors, while a third insulator, bolted to the top of the rail, carries a telephone wire connecting the generator-house with the dredge, the length of line being about 2 miles. Between the ends of the conductors on the bank and the motors in the dredge the two cables consist of seven No. 16 copper wires, and are heavily insulated with vulcanized india-rubber. The shore ends are clamped to the conductors near to one of the poles, a supplementary pole having to be used occasionally when the river-bed is too wide to admit of a single span to the dredge. The other ends of the cable pass over insulated pulley-blocks and are coiled upon a drum so that they can be drawn in or slacked out as the dredge moves towards or from the shore.

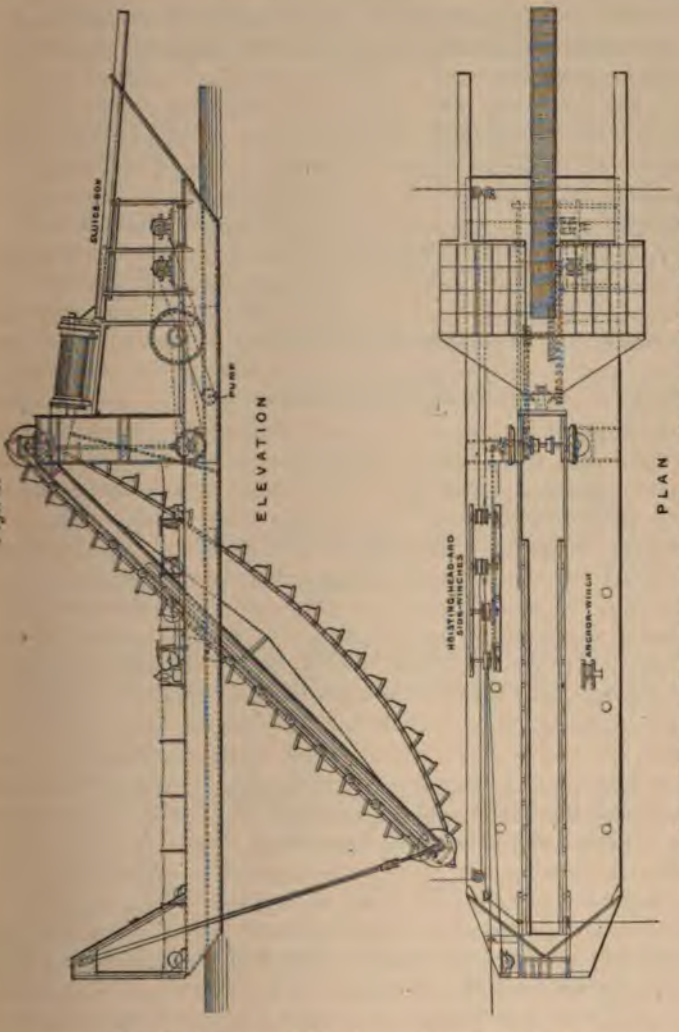
The electric motors, of which there are two, are also arranged in series and are exact duplicates of the dynamos, the object being to make the various parts of the machinery interchangeable, and to avoid a multiplicity of spare apparatus. A spare armature

and field-magnet are provided which will fit any one of the machines. One motor drives directly, through a belt, a centrifugal pump; whilst the other, geared to an intermediate shaft, drives the buckets, winches and revolving cylinder of the dredge, *Figs.* 2. As it is sometimes necessary to vary the speed or to stop the motor that works the buckets, a variable iron-wire resistance is provided by which its field-magnet coils can be shunted. The motor that drives the pump acts as a current-regulator, for, when the bucket motor is switched off, or its speed varied, the pump motor absorbs the surplus electrical energy—revolving faster and causing the pump to throw more water, which, however, does not cause inconvenience. By this means great simplification in the working of the plant is attained—an important factor when electrical apparatus is placed in the charge of unskilled hands.

The frames and plating of the dredge, which is 80 feet long and 20 feet wide, are entirely of steel, and where possible all the framing, ladders, buckets, &c., are constructed of the same material. The buckets, which have each a capacity of 3½ cubic feet, are filled and discharge at a rate of about 12 per minute. This gives a lifting-capacity, while dredging to a depth of 20 feet, of more than 90 cubic yards per hour, which is as large a quantity as can be economically treated on the tables for gold-saving purposes. The winches have separate barrels for the quarter, head and hoisting lines, which are of steel wire, and each barrel is driven by a large worm-wheel. A vertical shaft carrying a worm-wheel is connected with bevel-wheels below the deck, which are provided with friction-clutches so arranged that the barrels can be thrown in or out of gear by moving the winch handle to one side or the other, all the winches being driven by a shaft below the deck. The dredgings, boulders and gravel are delivered into a revolving cylinder 10 feet long, constructed of bars set ¼-inch apart. Through these bars the gold and finer sand pass on to the tables, the stones and debris being retained and afterwards discharged direct into the river through the stone-shoot. The tables are set at an inclination of 1 in 12 and are covered with baize upon which the gold is caught. The cloths are washed into tubs at intervals of eight hours and are then replaced on the tables. A 16¼-inch centrifugal pump, driven at a speed of 600 revolutions per minute and with a lift of 16 feet from the water-level, supplies about 2,000 gallons of water per minute to the revolving cylinder.

The dredge is lighted by two 10-ampere Brush arc-lamps included in the power circuit in multiple-series with the motors. They are controlled from a small switch-board on the vessel. A

resistance-coil to take 20 amperes is arranged as a shunt on the lamps, while the remaining 20 amperes is divided equally between two circuits, in each of which an arc-lamp is placed. The switches



Figs. 2. Gold-Dredger Employed on the River Shotover, New Zealand.
Scale, 24 feet to 1 inch

are arranged so that if one of the lamps is switched off an equivalent resistance is thrown into the circuit in its place, the current in the circuit of the other lamp remaining unaltered. When the lamp is switched off it is entirely disconnected from the power

circuit, so that it may be touched without danger of unpleasant shock. A third switch disconnects the resistances and lamps from the power circuit during the daytime, when the lamps are not required.

The full available output of the plant is not utilized, and a reserve of power is always maintained. The working duties of the plant as observed are :—

Pressure of water in the pipes	228 lbs. per square inch.
„ „ at the valve	195 lbs. „ „ „
„ „ at the nozzle	188 lbs. „ „ „
Speed of the Pelton wheel	447 revs. per minute.
Water used per minute	108 cubic feet.
Power developed by the Pelton wheel	88 HP.
Total electromotive-force of the dynamos	1,170 volts.
Total current „ „ „	30 amperes.
Total electrical output „ „ „	47 HP.
Loss of power transmitted through 2 miles of line.	5·2 HP.

The cost of the entire installation was :—

	£.
Dredge	2,600
Race and flume	500
Intake, pipes and valves	600
Electrical plant	2,500
Cartage of material to the site of the works	800
Total.	£7,000

The cost of working the machinery with three shifts of eight hours each, as obtained from the results of three years' work, has been :—

	Per Week.		
	£.	s.	d.
Wages, including dredge-master and electrician	25	0	0
Renewals, maintenance, oils, brushes, &c.	5	0	0
Management, office, rates and taxes	5	0	0
Total cost	£35	0	0

The Paper is accompanied by five sheets of tracings, from which the *Figs.* have been prepared.

Discussion.

Sir Benjamin Baker, K.C.M.G., Vice-President, in asking the members to pass a vote of thanks to the two Authors, said he should not make that proposition with equal confidence if he were addressing a meeting of agriculturists, because in the present depressed state of agriculture such a meeting would not perhaps receive with enthusiasm the work of Mr. Robertson, who, it would be observed, had dispensed with £1,200 worth of oats and hay, and substituted £500 worth of coal and oil. Agriculturists, however, had their revenge on the colliery proprietors in the second Paper, where it would be observed not only was there nothing for the agriculturists, but nothing for the colliery proprietors, for the Author had dispensed with coal altogether and had resorted to water power. At a meeting of engineers, however, instead of detracting from the merit of the Paper, the fact that the labour of agriculturists and colliers was dispensed with no doubt would add considerably to its interest. Both Papers were thoroughly up-to-date, and it would have been quite impossible that they should have been read a few years ago. He therefore thought that both the Authors were well deserving of a hearty vote of thanks. Sir Benjamin Baker.

Professor George Forbes said the two Papers had reference to extremely interesting applications of electrical power to special uses. Each arrived at the special results for the particular case in a different manner, and each, for that reason, deserved consideration on its own merits. Both Papers were differentiated from any large generation and distribution of power for a variety of purposes. In the latter cases care must be taken to arrange the system of distribution so that the current which was received by different consumers might be available for all the purposes for which it might be required, whether in the form of continuous current or alternating current, at high voltage or low voltage, and, in some instances, at either high frequency or low frequency of alternating current. In each of the present Papers, however, the special conditions which were offered had simply to be dealt with. With reference to the second communication, which dealt with a very interesting application, there were one or two points which he thought deserved particular attention, and which would be of use as a guide for similar work in the future. A description was given of an automatic appliance which had been introduced to Prof. Forbes.

Prof. Forbes.

prevent damage to the generators. An electro-magnetic appliance was arranged so as to prevent any accident when the current either exceeded or fell short of its normal amount by 10 per cent. In that case the circuit was broken, and the dynamo was set to work upon an artificial load equal to the normal load of the dynamo. By those means the over-heating of the armature was prevented. He thought that was a great step in advance of the usual practice of introducing a fuse, which would to a certain extent perform the same function. The only objection to the arrangement was, that, while it was perfectly satisfactory in preventing the dynamo from being injured by an excess of current from a short circuit over-heating it, and so burning it out, the act of suddenly breaking the circuit introduced a serious strain upon the insulation. He would therefore recommend the introduction, if possible, of a variable resistance at the moment of changing over from the line to the artificial load. Either a water resistance or a carbon resistance could be used for the purpose. The next important point was the arrangement for governing the system. The Pelton wheel had no efficient governor, and a difficulty had arisen in many electrical installations in enabling the power to be used either for a single purpose, such as the pump, or for a double purpose, as the pump and the dredging-machine. To mention a specific case, he might refer to the Calumet and Hecla Mines, where that difficulty had been encountered. A plant had been erected at considerable cost to drive a pump when it had been found unnecessary for the pump to be always working at full speed, and at times the current was required for hauling on a small tramway. The contractors had suggested joining another motor for the traction in parallel upon the line. That had been a complete failure, and one of the causes which had led to the use of electricity being abandoned in the mines. The difficulty had been that the HP. employed in the pump was of course a product of the speed and the resistance offered—in that case the head of water. The HP. was also the product of the volts multiplied by the amperes. It was stated as a broad generalisation that the speed depended upon the pressure, and the resistance which could be overcome by the motor depended upon the current. In the arrangement employed with the two motors in parallel, the same pressure was constantly employed; in other words, the pump was always working at the same speed; and since the head was constant it was not possible to diminish the power. That could only be done at a great sacrifice, and it caused both motors to work inefficiently. The

method introduced in the present case was clearly the solution of the difficulty, viz., to couple the motors in series. As soon as the dredge began to work, the electromotive force which was available for the two motors was divided between them; the pump motor received less electromotive force than before; it therefore worked at a lower speed, and the same current still passed through the wires, and accordingly it was able to work against the same head of water. Those two points in Mr. Hay's Paper, he thought, were very interesting. Prof. Forbes.

The Paper by Mr. Robertson was also of great importance, because it was a step in the right direction—a step which would be largely taken in the future. He had listened with great interest to the Paper, and he thought it would be admitted that the plant had been most successful, and had given satisfaction to everyone concerned in it. He should like to ask the Author to go a step further in the comparison of costs which he had made. He had given a comparison of the cost of traction by electricity and by horses. It would no doubt have been possible to have worked that part of the colliery, as the rest was worked, by steam direct with a cable, and, if so, it would be interesting to know the comparative cost of electricity and steam to work the plant. That was a question which colliery proprietors would naturally ask instead of always comparing it with horses. The cable described was a new arrangement to him. In the case where there was a V with two long legs to be served, and where the cable was led first up one leg of the V, then back again, then round a pulley and over the other leg of the V, and back again, it seemed to be an extremely satisfactory arrangement. As far as he could judge, no provision was introduced, and, therefore, he supposed, none was required, for taking up the slack of the cable. He should like to ask if that had been found unnecessary, or if there was any arrangement for the purpose. In the case of a pioneer installation for haulage in coal-mines, he would not wish to be critical, and he felt sure that the arrangement was a very satisfactory one. Although there was no risk of fire-damp, it had still been found desirable to enclose the electrical machinery in an air-tight compartment, to prevent the risk of explosion from the sparks of the commutator where the brushes rubbed on it. At Earnock that might not have been a matter for consideration, but in a large number of collieries it might be of great importance. Another thing which occurred to him was that the continuous-current motors, with their commutators and brushes, were liable to sparking, and required a certain amount of attention; and if the place were not well lighted, the

Prof. Forbes. chances were that they did not receive the requisite amount of attention. He should like to direct attention in future work of that kind—and most especially in fiery mines—to the possibility of using a poly-phase alternate current system for two- or three-phase motors. In that case there were no brushes on the commutator, and, in fact, no commutator at all. The current which came from the generator passed directly into the field-magnets, and produced currents in the armature only by induction, and there was no contact between the armature and the rest of the machine, except at the bearings. There was not only no brush and commutator, but no collectors, as in ordinary alternating-current machines. There were several important consequences arising from that. In the first place, a high-pressure current could be used to supply the field-magnets; that was, the massive conductors could be dispensed with and conductors of considerably smaller capacity used. The most important features, however, in connection with such a system, were, first, the abolition of the one weak point of continuous-current machines, viz., the commutator and brushes, and, secondly, the remarkably small amount of attention required for keeping the motors in order. He thought those two advantages, especially in a coal-mine, would commend themselves to all practical men. He did not, however, say that that system ought to have been adopted in the present case; he simply mentioned it as being worthy of consideration in the preparation of schemes for the future, and especially those in which there was any amount of fire-damp.

Dr. Foster. Dr. C. Le Neve Foster remarked that in listening to Mr. Hay's Paper his feelings were somewhat like those of Oliver Twist; he felt inclined to ask for more. The lifting capacity of the dredge had been given by the Author, but the amount of work that had actually been realised in practice had not been stated. He would like to know the amount of gravel, in cubic yards or tons, raised per day or per week, and also the yield of the gravel in gold, so as to compare it with the weekly cost which had been given in detail. He should further like to know the reason of the bucket-dredge having been chosen in preference to suction-dredges, which, like the bucket dredges, had been successfully employed in New Zealand. Possibly the reason had been that the gravel to be dredged contained a large number of boulders and stones which would render the suction-dredge less suitable than the bucket-dredge; but that was not stated in the Paper.

Mr. Atkinson. Mr. Ll. B. Atkinson had been concerned in connection with Mr. Robertson in the building and partly in the design of the

electrical haulage-plant at Earnock Colliery, to which his observations would be mainly directed. There were one or two points connected with it that had not been fully dealt with, and the reasons why certain arrangements had been adopted might be of interest. It might be of interest to refer to a Paper[1] read before the Institution in 1891 by his brother and himself on the question of electrical mining-machinery, because one of the points there laid down as in their view likely to attract the attention of engineers had been the importance of the position that electricity was likely to take in coal and other mining in the early future. Though that had been only three years ago, the position which electricity had already taken was remarkable. At present he supposed that no large applications of power to mining were made without, at all events, electrical application being seriously considered. It was also interesting to note that with few exceptions, Professor Forbes having noted one, all who had applied electricity to mining had not felt inclined to go back to any other system of transmitting power in their mines. The questions of safety and danger in coal-mining had been considered at the outset to be one of the great difficulties in the matter. In the Paper to which he had referred, he and his brother did not take the same view as to the extreme danger to be anticipated, and he did not think the question of the danger of electrical plant was an important one with the proprietors or engineers of mines. No doubt wherever there was mechanical power there was more danger than where manual or animal power was employed. He knew of no case in which any accident had been caused in a coal mine by electrical plant: on the other hand, there had been within the last two years one fire in a colliery caused by the overheating of the brake-blocks on the drum of a steam haulage-engine. Of course the number of steam plants was in excess of that of electrical plants, but the danger question had really become insignificant. He had been recently speaking to one of the largest colliery viewers in the North of England, in whose opinion the dangers of electrical plant were less than those daily incurred by the use of explosives in mines, and also less than the danger from using ordinary safety-lamps where the glass might be broken at any moment and the flame exposed to the atmosphere. He wished to call special attention to the arrangement of the engines, Fig. 2, Plate 2, in which two high-speed engines, one at each end of a shaft carried on independent pedestals, were used for driving the

Mr. Atkinson.

[1] Minutes of Proceedings Inst. C.E., vol. civ. p. 89.

Mr. Atkinson. dynamos. He had been asked on several occasions why the dynamos were not coupled direct to the engines. There were two reasons; the first and most important being that by the arrangement shown in the Fig. with clutches at each end, either engine was available for driving all or part of the plant, so that there was really a spare engine for every dynamo. There was only one power-dynamo shown in the Fig., but in similar installations with Willans engines and also with the Grafton engines, two dynamos were installed, so that in the event of either having to stop for repairs or otherwise, the other was available for any of the dynamos. Of course the efficiency was not quite so high, with a belt to drive, but the friction of the belts did not prove in practice to be large, and it was a great convenience and economical in the first cost of the plant. Another reason for adopting that method was that there was some difficulty with high-speed engines, particularly with throttle-valve governors, in cases where the loads were thrown on and off as rapidly as they were in the case of power-plant. In lighting-plants, loads came on and went off gradually; but in power-plants, haulage in particular, the loads would come on and off suddenly. The load was constantly being put on and off, and with direct-coupled machines there was a tendency for the engine momentarily to be stopped, the result being a fall in pressure with the shunt-wound dynamos or compound-wound dynamos, and there was an excessive current before the engine got away to action. That appeared to be overcome to a considerable extent by the use of belts, because there were more fly-wheels and pulleys moving, and also the dynamos could be driven at a higher speed, and there was also the elasticity of the belt. That was an advantage, in addition to the other point he had mentioned. The use of throttle-valve governors for that class of work was not altogether satisfactory, especially when driving pumping-plants from the engine, the reason being that at starting the load required was much greater than at any other subsequent period of the run, and if the engine had not a great margin of power, there was with throttle-valve engines, in which the cut-off and the consequent power was limited, a difficulty of getting the engine started. That did not occur when automatic expansion-gear was used, as, if necessary, this would give steam throughout the length of the stroke. That point had been mentioned by Captain Sankey in his recent Paper[1] before the Institution of Mechanical Engineers, and it was one which had

[1] Read February 1st, 1895.

caused in some pumping-plants considerable trouble. The continuous-rope system of haulage was no doubt most economical both in cost of working and in cost of plant where it could be adopted; but it necessitated a double load, which was not always available. The continuous-rope system was not really a good example of continuous haulage, because, as the Author had explained, the rope was loaded with five or six tubs at a time, often in one place, and not distributed evenly over it. That had an important bearing on the question of rope-friction, the amount of which he had in several instances tested with a rope of about $\frac{5}{8}$-inch or $\frac{3}{4}$-inch diameter, taking as a convenient unit the tension necessary per yard of rope run, he had found where the rope was on the floor, or even on pulleys and running with no other load than itself, the friction would vary between 0·5 lb. and 0·85 lb. per yard length of rope. That figure always decreased somewhat, according to his experiments, when the load was on, no doubt because the tension on the rope lifted it off the floor, and it ran only on the pulleys; it remained however, and in the present case the rope-friction was a large portion of the total load. Where the rope was placed above the tubs, these being connected at intervals of 30 yards regularly along the rope, it was obvious that the rope was carried on the tubs, and then no friction was caused by the rope, the only friction being that due to the wheels, &c., which there would be in any case. Therefore, to carry the continuous haulage to its most economical limits the ropes should be, if possible, on the tops of the tubs, which should be dispersed at regular intervals along the ropes. Mr. Atkinson.

In connection with the question of electrical haulage, he had placed on the table several photographs showing a different system of haulage—the main- and tail-rope system—which was in use in the Trafalgar colliery in the Forest of Dean. The engines were horizontal, driven by ropes and fitted with automatic expansion-gear, with a modified Proell governor. They were 18 inches by 36 inches, double-cylinder engines, and were working at 150 HP., with steam at 50 lbs. per square inch pressure. The engine was ready to work at 264 HP. when driven with steam at 80 lbs. per square inch. He had recently, in conjunction with Mr. Le Neve Foster, the engineer to the company, and Mr. Brain, the managing director, made some experiments on the power of the plant, and this interesting result had been obtained; that having a given load and a given number of tubs on the rope, it required less tension in the rope to drive the machinery and run the tubs at 5 miles an hour, than it did to run them at $\frac{1}{2}$ mile an

Mr. Atkinson. hour. The only reason he could ascribe was, that at ½ mile an hour the speed was so low that the oil was squeezed out from the tops of the journals of the tubs, and consequently they were running almost with dry friction and not with thoroughly lubricated bearings. It was generally supposed that the tension of the rope would increase considerably with the speed, but there was 20 per cent. less tension in the rope when driven at 5 miles an hour than when driven at ½ mile an hour. The maximum power to which the plant was worked in the course of those tests was 130 HP. delivered into the motor, the probable efficiency of the whole machine being between 75 per cent. and 78 per cent. The question of two- and three-phase motors in mining work had been referred to by Professor Forbes. It was a question which was often raised, and there was a reason why, so far, he, at all events, had not seen his way to adopting two- and three-phase motors for that class of work. Stress had been laid on the fact that the revolving part, corresponding to the armature in a continuous-current machine, had no commutator and no brushes. Of course, it was possible to make a three-phase or a two-phase motor start and run without brushes, but in order to obtain a large starting-effort it was necessary, if not to have a commutator, to have slip-rings and brushes to enable resistances to be inserted, or otherwise the armature reaction at starting —that was at low speed — was so great that the power put in was largely in excess of what was required for the work. The brushes and slip-rings had to be dealt with instead of a commutator. Then arose the question, supposing the motor to be started and running, and the load to be rapidly thrown on and off without an attendant being near; the resistance was thrown out from the armature, and the same difficulty as at starting seemed to be presented—that when the speed was reduced by throwing on a heavy load suddenly, there were not the means of obtaining the large starting-efforts that were required in haulage, or particularly in a case where it was very desirable, that of coal-cutting machinery. All the tests hitherto published of two- and three-phase motors showed the currents required at starting to be very large. The only way to obviate this was to leave the resistance permanently in the circuit, either in the armature or outside, and be satisfied with an efficiency of 80 per cent. instead of 90 per cent. or more. Even taking two- and three-phase motors with resistances in them the starting-moment, at the maximum, was twice or two and a half times as great as for the full load, and that was not enough, even for coal-cutting machinery, or for hauling machinery,

to start heavy loads. He had only indicated those points in order to show that there was a difficulty in getting a really heavy turning-moment to start with. Mr. Atkinson.

Mr. E. R. Dolby congratulated Mr. Robertson upon his good fortune in having met with a company of colliery owners who were prepared to spend the considerable sum that had been mentioned. He had had nothing to do with Scotch colliery owners, but he knew that those in the Midlands were in the position of the agriculturists mentioned by Sir Benjamin Baker—passing through a sort of hand-to-mouth existence, so that, if a complete scheme were placed before them, they would say it was impracticable, because it would cost far too much. A piecemeal scheme had therefore to be resorted to which did not give satisfactory results. Colliery owners usually wished to instal plant for lighting pit-heads and banks, and to do that they needed merely a compound-wound dynamo. Then, when it was found that the dynamo was only working during the evening, they wished to put on lights below at the pit-bottom, and perhaps to add a small pump. It was obviously impossible to get satisfactory work at the pit-bottom with a machine which was not over-compounded. For top-lighting the pressure would be only about 220 volts, with two lamps in series, which was not sufficient for a large output at the bottom. The case mentioned in the first Paper was an ideal one, where the engineer appeared to have been empowered to do what he liked. It was stated that the dynamo was compound-wound. He presumed that meant it was over-compounded, for he observed that shaft No. 2 was 240 yards deep, and the resistance of the 480 yards of 19/14 cable was 0·12 ohm. At the foot of the shaft that cable divided into two parts, and from the foot of shaft No. 2 to A, Fig. 1, Plate 2, and thence to E, where one of the hauling-engines was placed, the distance was 2,500 yards, giving a resistance of 0·975 ohm. He also found on the other branch, which went by N O P Q to R, the length was about 1,100 yards, so that the resistance was 0·937 ohm. Therefore he supposed the dynamo was over-compounded to give a constant potential at the hauling-engines. It was further stated that the hauling-engine at E required 76 amperes. This current flowing through a resistance of 1·09 ohm, would give a fall of potential of 83 volts, which was approximately that stated by the Author. From the figures in the Paper it appeared the efficiency of the hauling-engine at E was about 86 per cent., and the maximum current density in the 19/14 cable was about 1,050 amperes, in the 19/16 about 1,200 amperes, and in the 7/15 about 900 amperes per square inch. In Fig. 4, Plate 2, there was a Mr. Dolby.

Mr. Dolby. view of the gearing between the motor and the hauling-engine shaft. He observed that the Author had used gearing, and he should like to know if he had had any experience with friction-gear for such purposes. He had no experience of electrical hauling-engines; but he had made a considerable number of tests with cranes which were somewhat similar, and had found that with friction-gear, when using a shunt-wound machine and an armature running constantly, the starting current was considerably less with the friction-gear than with a similar machine with any kind of spur- or helical-gearing that he was aware of. In that way the series of resistances which it was necessary to insert at starting could be dispensed with, because, when the armature was turning there was a proper back electromotive-force. Dealing next with the small motor at R, if the same efficiency of 86 per cent. were obtained, it needed a current of 26 amperes—76 and 26 making 102, so that it appeared the total current given out by the dynamo was just sufficient for the two machines, if they were both working together at their maximum. The dynamo worked at 490 volts, and that gave about 65·7 electrical HP. If the efficiency was 90 per cent. it gave a HP. of 73 for the engine. The two engines were stated to give 122 HP. If both were the same size, one would only give 61 HP. He should be glad if the Author would state whether one engine was sufficient to drive the two hauling-engines, because that was an interesting feature. There was no statement of the insulation-resistance of the cables. That, he thought, was an important point. It was stated that the cables were led down the shaft in iron tubes. He supposed that the two cables were not placed in one pipe, which of course would be a bad method; but even if they were placed in separate tubes, he ventured to think it was not the best method, because although an iron pipe could be made watertight, if anything happened to the cage the pipe would probably get bulged, and there would be great difficulty in repairing the cable. He should prefer a casing with a strong fillet between the conductors. He should be glad to know if the conductors which were passed down the shaft were supported in any way, because if not there would be great stress on the upper portion, due to the weight of the pendent cable. The sum expended was said to be £3,500, but he did not think it was clear whether that included the two engines, or merely one engine with half the shaft.

Dr. Preller. Dr. Du Riche Preller remarked that the plants described in the Papers were no doubt both instances of transmission of power by electricity, but he thought that as transmissions of power by elec-

tricity they could not be called typical instances, since the distances of transmission were, comparatively speaking, short—in the first case 1 mile, and in the second 2 miles. It was well known that electrical energy was transmitted to much greater distances—to 10, 20, and 50 miles, and at Lauffen and Frankfort even to 100 miles. Again, in both cases, low tension of 450 volts to 650 volts was adopted, while in alternating-current installations the tension varied between 2,000 volts and 10,000 volts; and in some direct-current transmissions tensions as high as 5,000 volts were used. It was desirable Mr. Robertson should compare not only animal-power and electricity, but steam-power and electricity. It was well known that in mining operations, where steam-power and compressed air were employed, there was great waste of power, and he had no doubt that by a comparative statement a great saving could be shown in favour of electricity. He noticed that the losses in the engine-room, mentioned in Mr. Robertson's Paper, were 22 HP. out of 122 HP., giving 80 per cent. efficiency. He did not think that the loss in transmission was stated. If that were taken at 5 per cent., it would bring the efficiency down to 75 per cent., and if 15 per cent. only were taken as the loss in the motors, that would bring it down to 60 per cent. for full load. It might be therefore taken that the total average efficiency of the plant worked out at about 50 per cent. For direct-current machinery he thought that was a fairly satisfactory result. He was exceedingly glad to hear some remarks that had been made with regard to the question of direct and indirect driving. He quite agreed that, where there were many fluctuations of load, direct driving would not be advisable, although, of course, in principle, it should always be aimed at. For future works of that kind the application of alternating-current machinery had been recommended, but Mr. Atkinson had afterwards remarked that even with alternating-current motors, commutators and brushes could not be dispensed with. That, however, was no longer the case. In the original single-phase synchronous alternating-current motors, it was necessary to have commutators and brushes; but in the new type of non-synchronous, self-starting motors that was entirely done away with, and the difficulty had been solved by introducing an additional coil, which in the case of a single-phase motor acted only at starting. In that way the commutators and brushes were entirely dispensed with, and an alternating-current motor which weighed only about two-thirds of the direct-current machine of the same output or power, and was infinitely more simple and

Dr. Preller.

Dr. Preller. manageable in every way, was secured. Poly-phase, viz., two- and three-phase motors had been especially recommended by Professor Forbes; but he wished to point out that single-phase alternating-current motors had been so improved, and brought to such a state of perfection, that they could be relied upon for developing the same amount of work, and as efficiently as the two- and three-phase motors. This was proved by the large number of such motors used in various countries for a great variety of industrial purposes. With regard to the question of the cost of installation in Mr. Robertson's Paper it worked out at £30 per HP., which was moderate. The cost of the plant described in Mr. Hay's Paper, including the dredge, worked out at the high figure of £100 per HP. It must, of course, be remembered that that was in New Zealand, where labour and transport were more expensive. Exclusive of the dredge, the cost was £63 per HP., which he thought would correspond in this country to the figure named in Mr. Robertson's Paper—£30 per HP. In connection with the New Zealand transmission-plant there was stretched on the top of the naked conductors a telephone-wire. That, he thought, was dangerous, because, when such a wire, mounted above a naked conductor, broke and fell on to the naked conductor, even with a voltage of only 500, serious consequences might follow. He remembered one case, when he had been in the Tyrol some years ago, at Innsbruck, where there was a high-tension (5,000 volts) plant for power transmission to a distance of about 5 miles. A telephone-wire had fractured, owing to the weight of snow, and, in falling, coiled round the conductor, the end of the telephone-wire resting on the ground. A man had happened to pass, and touched the telephone-wire end with his foot so as to remove it, and he had been instantly killed, due entirely to the fact of the telephone-wire being stretched on the top of the transmission conductors. Considering that both the installations under discussion were situated in hilly or mountainous districts, he should be glad to know if there was any protection against lightning discharges. It was well known that mountainous districts were subject to violent atmospheric discharges. He had lately had occasion to give attention to that subject; and particularly in the case of mining operations, where there were motors in the mines themselves, great danger might arise, not directly from lightning discharge, but from the dynamo current following the atmospheric spark and forming an arc, which was certain in the majority of cases to short-circuit the dynamo or motor. He thought that was an important question which was often neglected,

and he should like to ask the Authors if there were any lightning arrestors on their lines, and if so of what kind. Dr. Preller.

Mr. E. C. De Segundo, with reference to the point raised by Mr. Dolby as to the I.HP. of the engines, supposed that 122 was the I.HP. of the two engines together. That gave a low efficiency of the dynamo, and he wished to ask whether the figures were right. As far as he could determine, the electrical efficiency of the dynamo was not more than 70 per cent., which was certainly low for a 60-kilowatt machine. Some time ago he had carried out a number of experiments to determine the actual efficiency of the Pelton wheel when coupled direct to a dynamo, and he had never succeeded in obtaining a combined efficiency of more than 60 per cent. The Pelton wheel and the dynamo had both been specially constructed to suit the great head of water at which they were intended to work. He had made several attempts to accurately measure the HP. of the wheel; but, owing to the high speed (1,660 revolutions per minute), accurate measurement was difficult, and he had to resort to the combined efficiency as a means of determining the mechanical efficiency of the wheel. The dynamo was not well suited to the wheel, as the power of the latter was about 50 per cent. in excess of that which the dynamo was intended to develop. The commercial efficiency of the dynamo had been stated by the makers to be 85 per cent. The highest combined efficiency observed had been about 56 per cent.; hence the efficiency of the wheel, including journal-friction of the dynamo, would appear to have been $\frac{56}{85} \times 100$, or about 66 per cent. Now, taking Mr. Hay's figures, namely, a consumption of 108 cubic feet of water per minute, at a pressure of 188 lbs. per square inch at the nozzle, the HP. in the water would be 88·5; but the wheel was stated to yield 88 HP., which corresponded to an impossible mechanical efficiency. It would seem that one or other of these measurements was inaccurate, and that the pressure-gauge, or the water-meter, or whatever apparatus had been employed for the measurement of the water-consumption, was at fault. In order to obtain the highest efficiency, the peripheral speed of the wheel should be one-half that of the water due to the head corresponding to the pressure at the nozzle. The effective diameter of the wheel might be assumed to be 4 feet, and this would give, at 447 revolutions per minute, a linear velocity of 5,614 feet per minute in the buckets. The velocity corresponding to water under a head producing a pressure of 188 lbs. per square Mr. Segundo.

Mr. Segundo. inch was 9,936 feet per minute; hence the wheel was not being worked at quite the proper speed for maximum efficiency. It was possible that the pressure recorded near the nozzle was a fictitious one—all the more so if the gauge were placed at a little distance from the nozzle and near the valve. He had found under those conditions that the gauge-readings were unreliable. Immediately after passing through the valve, when not turned full on, the pressure of the water fell greatly; but other observations pointed to the fact that the pressure must have recovered, as it were, after passing the gauge. It had been found that high-pressure water, in passing through a restricted portion of a tube and flowing into a portion having a larger sectional-area, did not rise to its full pressure all at once, but "recovered" a few feet further on. He should like to ask the Author to verify or correct the data, because the question of the Pelton wheel as a source of motive power was an interesting and important one. If that wheel could be made to work efficiently there was no doubt there would be a large field for it; but at present the real mechanical efficiency of a Pelton wheel at high heads was problematical.

Mr. Robertson. Mr. ROBERTSON, in reply, dealt first with a point of great importance—the comparison between the costs of haulage by steam and electrical haulage. The question of extending steam haulage in the present case had been well considered, and the objections against it had been the following. The steam hauling-engine situated at B operated the road, about 1,200 feet long, between B and F shown in Fig. 1, Plate 2. Between B and C, and between D and F, the gradient was with the load, but between C and D there was a considerable length of 1 in 12 gradient against the load. That gradient against the load limited considerably the length of the train which could be drawn along the road with the main- and tail-rope haulage. The present hauling-engine was one of the largest used for that class of work. It was made with four pairs of drums for working other main- and tail-ropes in different parts of the mine, and it was impossible to put any additional load on to that engine. If a new steam-engine had been installed near the bottom of the shafts where steam could be taken conveniently, it would have been necessary to carry the haulage ropes throughout the whole length of 1,200 feet to F before any useful work could be done in supplementing the plant at present in use. As the motor had to be placed at some point near the end of the existing hauling

plant, and the power conveyed the distance of the depth of the shaft in addition to the length of the 1,100 feet to the point E, it was considered impossible to carry steam so far as to work a steam-engine economically at that point. The only other question had lain between electricity and compressed air. In considering those two methods the initial cost of a compressed-air plant for the same power had been found to be much greater than an electrical plant. As to the slackness of the cable, he thought Professor Forbes had omitted to notice that there were balance-wheels shown on the enlarged plan at the point E, Fig. 3. In the recess opposite the engine-room there were two wheels mounted in the usual way on carriages. Those carriages had a chain passing over two pulleys with a balance-weight of about 10 cwt. to keep the tension on the out-going end of the rope. The question of explosion was one which was not considered so much now as it had been when electrical plant had been introduced into mines. The dangers were not so serious as had been at first supposed. In order to avoid all appearance of danger in this instance, in both cases the plant was placed in the fresh-air intake, so that although the motors were in a neighbourhood where there was fire-damp, their being in the fresh-air current would render the chance of their giving rise to explosions very small. Reference had been made to the question of using an intermediate shaft; the object of that had been to have duplicate engine power. The question of the power had been referred to, and he would therefore take up that point. The engines each developed 61 brake HP., and although with the two motors working at full load the power dynamo alone would require about 80 brake HP., it was found in practice that one engine was sufficient to give the whole of the power required for hauling. The only occasion when both engines had to be working together was in winter, when the lighting dynamos (which were not used for pit-lighting, but for lighting two large mansions in the neighbourhood) had to be started before the haulage was stopped. It was then necessary to work the two engines together, as the three dynamos required more power than one engine was able to give. The system of putting short trains of six hutches on the endless-rope at one time had been referred to as not being a fair example of endless-rope haulage. There was no doubt that that put additional work on the motors, but in arranging the system to be adopted that had been carefully considered, and the objection to coupling the hutches on singly and approximately at equal dis-

Mr. Robertson.

Mr. Robertson. tances, had been the additional number of men required to work where there were so many junctions and so many branches. It was necessary to have at least one or two men at those junctions to relieve the hutches when they had to change from one branch of the rope to another where the rope was not continuous. At all points where the hutches had to be taken off and put on additional men were required. If the roads were not in good order, a large staff of men was required to be continually passing up and down the roads to be ready to give the signal to stop the rope in the event of the hutches going off the road. In the other case, where hutches were conveyed in short trains, a man rode with each train. If any of the hutches went off the road, he immediately, by means of the signal wires alongside, signalled to stop the rope; he was on the spot and could get the hutch put on at once, and thus there would be no delay. With regard to the question of large expenditure, it might be interesting to remark that that colliery had not only been one of the earliest to introduce the haulage-plant, but fourteen years ago had erected an installation of electric-lighting at the same pit for lighting the offices, screens, and other parts of the work above ground, and for all the roads below in the immediate neighbourhood of the bottom of the shaft. The power-dynamo was over-compounded, to give as nearly as possible constant potential at the motors, although it was impossible to obtain this exactly, as the current used by the two motors did not vary proportionally. In that case, where the speed of the rope was so low, it was not a matter of great consequence, although it varied between $2\frac{1}{2}$ miles and $3\frac{1}{2}$ miles an hour, according to the load which was on the rope. He had not had any experience of friction-gear for such purposes; but his objection to introducing it in the present instance had been the difficulty in keeping it in good order underground where there was so much dust from coal, for it was apt to stick when it was not wanted to. The pipes in the shaft were simply for mechanical protection of the conductors, and were placed behind the frames supporting the guides for the cages, where there was no possibility of the cages coming in contact with them. The pipe was supported by junction-boxes dividing the height into several sections. He could not give the exact length of those sections from memory, but the pipe was supported frequently in the length of the shaft.

The total cost was divided among the various portions of the plant as follows:—

Mr. Robertson.

	£.
Engine-house at the pit-head, including foundations for engines and dynamos	517
Motor-houses underground in Ell and Main coal-seams, including cutting out coal, building brickwork and hauling-engine foundations	223
Two Westinghouse engines, shaft, belt, power-dynamo, 35 HP. and 12 HP. motors and hauling-engine, conductors, telephones, &c.	2,133
Wheels, pulleys, rollers, ropes, &c.	568
Spare armatures for power-dynamo, both motors, spare magnet-coils for both motors, spare contacts and barrel switch for large motor, and sundry spare brushes and stores	338
	£3,779

From the average of several tests the following were approximately the losses in the various parts of the plant, which showed as nearly as possible an efficiency between the I.HP. of the engine and power developed on the ropes of 50 per cent.

	Per cent.
Loss in engine	22·0
,, shafting	0·5
,, belt and dynamo friction	4·5
,, exciting dynamo	3·0
,, cable	12·5
,, motor and gearing	7·5
	50·0

No lighting arrestors had been applied to the conductors used for the power current which were exposed only between the dynamo-room and the shaft for a short distance, but they had been fitted to the overhead conductors for lighting in the cases in which the current was carried $1\frac{1}{4}$ mile and $\frac{1}{2}$ mile respectively.

Correspondence.

Mr. Thomas Gillott asked, with regard to the general arrangement described in the first Paper, whether there had been any particular reason for selecting the position E, Fig. 1, Plate 2, for the motor and gear, as it appeared, both from the locality and gradients (1 in 20 down to the pit), better to have extended the main- and tail-rope haulage from E to F, and have simplified the endless-rope gear and tightening arrangements by placing the drums on the roads at F (as at St. John's Colliery, Normanton),

Mr. Gillott.

Mr. Gillott. with direct leads for the ropes. He did not approve of the circuit of one rope, from J on to L, K, and back to the gearing, as a straight endless-rope from F to K driving a clutched branch drum for the road between J and L appeared a better arrangement, and was one which he had found to answer well. For such irregular work as haulage, with frequent stoppages, he preferred to drive the dynamo by an engine having automatic expansion-gear, and had found the engines with Hartnell gear highly satisfactory. At Messrs. Locke & Co.'s colliery there were four 50-HP. dynamos so driven, and this gear acted admirably when all the clutches for hauling were thrown out, and also on the breakage of a belt.

With regard to the electrical hauling-engines, he noticed that the armature-spindle was geared to the drums by helical spur-wheels; but his firm had found that gear-wheels caused a vibration which destroyed the insulation of the armature-coils, and for the first reduction of speed, belts were employed in all of the eight motors working at Messrs. Locke & Co.'s collieries, geared armatures having been abandoned. This arrangement rendered a longer motor-house necessary. Also with the drum shafts arranged horizontally he would have adopted drums of larger diameter than 4 feet 6 inches, to prolong the life of the ropes; and although Messrs. Locke & Co.'s drums were of the same size, they were horizontal, and of a diameter equal to the distance between the centres of the roads; but a larger diameter (6 feet or 7 feet) was preferable for a steel hauling-rope $\frac{3}{4}$ inch in diameter, and there seemed to be no reason why the Author should not have used larger drums. He considered the speed of the rope (3 miles per hour) too high, and that the work in driving the rope would be excessive. The speed was also too great for the convenient attachment of the tubs. In sets of six tubs with 12 cwts. of coal in each, one hundred and eleven sets were required for a day's work, or eleven sets per hour. Of this amount he assumed nine sets to pass from J to F, or one set every seven minutes. As the length of this portion was 795 feet and the speed 264 feet per minute, the rope, under the assumption made, was running idle on the most heavily worked road during half of the working time. He would be interested to know the results of the tests of the power required to drive the unloaded rope. Bearing on the subject he gave corresponding information from the trials he had made. The roads at Messrs. Locke & Co.'s colliery, when straight, were worked with the rope carried on the tops of the tubs, where the friction apart from the tubs could not be measured; but one district, 1 mile in length, with the rope under the tubs

and two easy curves in the length of the road, required for the empty gearing 10 amperes, and for the gearing and empty rope at a speed of 195 feet[1] per minute, 25 amperes, the pressure being 750 volts. This gave 15 E.HP., or 700 lbs. per ton of rope, for the work of driving the empty rope, and was by far the most important part of the whole power, which, for about the same output as at the Earnock Colliery, required 32 amperes to 48 amperes, according to the number of sets on at one time. He agreed in commending the Smallman clip, but asked whether back-clips were also attached on those parts where the gradient was in favour of the load, to prevent the tubs over-running the front clip and becoming detached. Mr. Gillott.

As regarded the general question of electrical transmission, he could speak favourably in every respect except that of first cost. For transmission alone, the dynamo, cables, motors, and accessories would not cost less, and would often cost more, than £20 per I.HP. in capital outlay. And although he could not suggest an alternative so generally applicable to the various requirements of a colliery underground, he would welcome something cheaper, especially as the tendency of legislation at present was to so reduce the work that could be done as to make extra capital charges an increased burden difficult to be borne.

Mr. J. A. Longden remarked that in the year 1890 the question of underground haulage at the Pleasley Colliery of the Stanton Iron Works Company had become so important that the relative merits of the four methods, viz., compressed air, belt-rope transmission down the shaft, steam underground, or electricity had to be carefully considered, with the result that electricity had been adopted. A dynamo had been supplied by Messrs. Crompton & Co. to develop 606 volts and 140 amperes, and placed on the surface with a motor of similar dimensions underground. Carbon brushes had been used, and no difficulty or stoppage had arisen during the four years the electric plant had been continuously running. The cables in the shaft were 1 inch in diameter and were placed in pitch-pine grooved casing with a cover screwed on the face. In the pit the motor, by means of belting, drove two six-grooved pulleys. The two main roads were driven by these pulleys with endless ropes, and the tubs were connected by Fisher hauling-clips. There were also three smaller motors developing about 6 HP. each, which drew the coal on three branch-roads. The pits Mr. Longden

[1] This was the speed at which the observations had been made; the speed when hauling was not more than 176 feet per minute.

Mr. Longden. at the top and bottom were lighted entirely by glow lamps, and the present load on the dynamo was about 80 amperes. The average quantity of coal raised daily during 1890 with fifty-four horses had been 850 tons, and the present electric plant was conveying regularly 1,700 tons in the same time and with no more horses.

The saving estimated by the Author was much greater than could be shown under similar circumstances in the Midland counties. The horse-keep and driver would there not cost more than one-half the sum the Author named, and the difference would just compensate for the saving he showed by the adoption of electrical plant. It would be impossible to work with double the number of horses at Pleasley, and the advantage of splitting up the power and working branch motors, pumps, coal-cutters, &c., rendered the electrical system much more convenient than others. The sparking was slight, and where safety-lamps were necessary the Stokes-Davis closed commutator could be used. The plant at Pleasley Colliery had cost about £3,000, exclusive of boilers, and the cost of working and maintaining it was much less than those the Author had stated.

Mr. McMurtrie. Mr. G. E. J. McMURTRIE considered that the successful application of electricity at Earnock Colliery to underground haulage was of much interest to all connected with coal-mining. A most important point was the first cost and working economy of the system as compared with those of the older system of mechanical haulage, viz., steam or compressed air. At the Foxes Bridge Colliery, Cinderford, there was one pit drawing 250 tons per day supplied entirely by mechanical haulage, worked by compressed air at a pressure of 50 lbs. per square inch. An upper plane, 600 yards long, was worked by a pair of 9-inch horizontal cylinders with 1 foot 3 inches stroke, geared 3½ to 1, and drawing twelve tubs on a journey. The tubs weighed 8½ cwts. and carried 22½ cwts. of coal. A lower plane, 800 yards long, was worked by a similar pair of engines with 14-inch cylinders and 2-foot stroke, drawing trains of twenty-four tubs to a siding. The system of haulage in both cases was the main- and tail-rope. The upper plane was principally supplied by the lower engine, but also drew coal from a siding a short distance above the lower-plane siding. The dip of both planes was 1 in 24 against the load. A self-acting incline about 300 yards long supplied the lower-plane, and horses drew the coal from the working places to the incline top. The yearly working-cost of the mechanical haulage alone was:—

Mr. McMurtrie.

	£	s.	d.
Wages of three enginemen, one fitter, one carpenter, two train-riders, and one oiler for 250 days	332	0	0
Coals, oils, stores, &c.	229	0	0
Ropes	104	0	0
Depreciation on two hauling-engines and two compressors, &c., 15 per cent. on £1,500	225	0	0
Total	890	0	0

This cost was equivalent to a little less than 3½*d.* per ton, or practically the same as that given in the Paper, if the quantity drawn at Earnock were 600 tons per day. But it should be observed that the first cost of the electric installation was £3,500 as compared with £1,500 in the case described, in which also the distance the coal was drawn was 1,400 yards as compared with an average distance of 560 yards at Earnock. The relative quantities drawn at Earnock greatly diminished the working costs.

In a second pit under his charge raising a similar quantity of coal, all the haulage was by horses, assisted by self-acting inclines and drop staples, the districts being too scattered to apply mechanical haulage and with gradients in favour of the load.

The cost in this case was :—

	£	s.	d.
Depreciation and renewal of fifteen horses, 15 per cent. on £450	67	10	0
Keep of fifteen horses at £36 per year	540	0	0
Wages of nine men and fifteen drivers for 250 days	1,041	13	4
Total	1,649	3	4

or equivalent to 6·33*d.* per ton.

This latter cost was a little less than the estimated cost of the work by horses at Earnock Colliery, which was now done by electric haulage. He wished to know how the efficiency of the Earnock haulage-plant had been obtained. The engines at the surface indicated 122 HP., and the losses were stated to be 22 HP. If this meant that of 122 HP. indicated by the surface engines 100 HP. was obtained as useful work in the hauling-engines, or 82 per cent. efficiency, he thought the Author was to be congratulated on the result. It would add interest to the Paper if the cost of the steam-haulage could be given. No doubt the application of electricity to the distant haulage-plant had been due to the desire not to take steam so far. It was an open question whether it had proved economical, and whether a compressed-air plant would not have been cheaper in first cost. Though the efficiency of the latter was relatively low, it

Mr. McMurtrie. possessed other advantages in the assistance to the ventilation and absence from possible dangers due to gas.

Mr. Snell. Mr. ALBION T. SNELL, referring to the plant at Earnock Colliery, was glad to note that the electrical haulage was by the endless-rope system, which, in his opinion, was the most economical, the least liable to mishaps, and gave the greatest possible output for a given power. In the electric hauling-plant which he had installed at St. John's Colliery, Normanton, in 1889, on that system, the motor had been designed for 50 HP., and the capacity of the two levels which it worked was about 800 tons per shift of eight hours. The dynamo and motor, however, were both series-wound. A compound-wound dynamo was necessary at Earnock, as there were two motors. These were shunt-wound, probably because it was feared that the load would vary within wide limits. He was in favour of series-wound motors for endless-rope haulage, as he had found the load on that system to be fairly constant. In fact, the power required to drive the rope was generally nearly as great when it was unloaded as when it was loaded, on account of the full and empty tubs tending to balance, and because the gradients had an equalizing effect. Also, if the rope were carried on the tops of the tubs, and these were well spaced, the friction of the rope on the rollers was then diminished, and so roughly balanced the load due to the weight of the tubs. The effect was not so marked when the rope was carried beneath the tubs, for then the rope ran on the rollers to a greater extent. He observed that the motors and regulating devices were enclosed in gas-tight casing. This was a good practice even in pits where naked lights were permitted, and should be a peremptory condition where safety-lamps were compulsory. With regard to the conductors, he was surprised that the distributing-cables in the levels had pure rubber insulation, although that of the shaft-cables was of vulcanized rubber. In his experience vulcanized rubber lasted longer and was more reliable. The statements of the prime cost of the plant and working-charges showed clearly how large a saving might be made by the substitution of electrical- for horse-haulage. Indeed, he considered that colliery proprietors could not afford to do without electricity.

The plant on the Shotover River was an interesting example of the utilization of waste water-power by electricity, and was notable as the first plant of the kind in New Zealand. The electrical details appeared to be peculiar. Regularity in the speed of the motor was evidently not required; but it appeared that the addition of a third wire, earthed at each end of the line, would be a decided

improvement. It would enable one motor to run independently of the other, and the maximum pressure between the earth and the line would be only half its present amount. He thought that the artificial line-resistance was a cumbersome method of controlling the dynamos and Pelton wheels. It must be recollected, however, that this plant had been erected more than three years ago. If the work were to be undertaken now, a three-phase alternate-current system would probably be chosen, and speed-regulation would be obtained in a different manner. Mr. Snell.

Mr. Wm. H. Booth observed, with regard to the second Paper, that the rate of bucket-travel was stated as twelve per minute. This was a usual speed for a bucket-dredger, but no evidence had ever been brought to show that it was a suitable one. It was a rate that might be found in dredgers of different sizes. With chains of 40-, 60- and 80-centimetre pitch, the number of buckets was the same—twelve, but the speeds for chains of these three pitches were 9·6, 14·4 and 19·2 metres per minute respectively. That was the speed of the cutting-edge of the buckets; and if 19·2 metres was a suitable speed for a large dredger, it should be a proper speed, or, at least, not too fast, for a smaller dredger, and the chain of 40-centimetre pitch would be expected to run at twenty-four buckets per minute. On a larger dredger within his knowledge the buckets had been driven as fast as twenty-four per minute with advantage, and the usual speed of twelve buckets per minute was certainly too low for many soils, such as silt, peat, soft clay, &c., for small machines. Even where lumps of rock were found the risk of breakdown was minimized by the slipping of the driving-belt. Again, the chains of bucket-dredgers seemed to be proportioned on the assumption that dredging was very hard work. Yet 30 I.HP. was sufficient to drive a dredger having buckets of 300 litres capacity and chains of 60-centimetre pitch, the latter consisting of 4½-inch by ⅞-inch flat links, four in parallel, and having a total cross-sectional area of 15¾ square inches. If the whole of the 30 HP. be transmitted through the chain, the stress at a speed of twelve buckets, or 48 feet, per minute, was only 1,301 lbs. per square inch of cross-section, and probably not more than 1,000 lbs.; and it would greatly reduce the weight of the chain and its wear in the pins and tumblers if the chain-links could be made of I section in the body. The dredge had been stated by the Author to deliver 1½ cubic yard per minute; yet with that small quantity of gravel, all of which would pass a ¼-inch grid, he used 12 cubic yards of water, or eight times the volume of the gravel and sand. Such a volume seemed too great Mr. Booth.

Mr. Booth. to secure the retention of the finer gold upon the blankets, and it would appear that much of the finer gold must be lost by such severe treatment.

The valley of the River Po, in Piedmont, was rich in gold; the tributaries of this river, as the Orco, the Dora Baltea, &c., flowed through alluvial plains from the mountains. The gold found was of the value of about 1·5 franc per cubic metre, and the inhabitants worked it at the rate of about 1 metre per day, and so earned 1·5 franc per day. A few years ago a Dutch syndicate had begun to dredge for gold. The water-level was uniformly 1 metre below the surface, and the dredger was built in an excavated pit, and simply dredged its way across country, filling up the hole it made with the tailings. A dredger that would treat 1,000 cubic metres per day could thus realise £40 to £60 daily for expenses and profit. The dredged material was discharged on a shaking sieve, large pieces being rolled clear. The sludge was then spread thinly on a sloping tray, 25 metres long and 3 metres wide, cross-grooved with riffles, $\frac{3}{4}$ inch by $\frac{3}{4}$ inch, separated by strips of the same dimensions. These grooves contained mercury, and they were kept stirred by a rake, the final clearing up of the table being treated in a revolving amalgamator pan, retorted, and sold. The amount of water used was 6 parts to 1 part of sludge.

Mr. Lockhart. Mr. WILLIAM S. LOCKHART remarked with regard to the information given as to the pipe-line, that two thicknesses of plate were given, indicating either that the pipes were all of one diameter with the 16 B.W.G. plates at the top and the 11 B.W.G. at the bottom, or that the diameter was reduced towards the bottom with the 16 B.W.G. plates below and the 11 B.W.G. at the top where the diameter was greater. He would like to know how this was actually arranged, and the positions in the pipe-line where the breaks in diameter or in the plating or both occurred. Since the plating was so light he supposed no sluice-valve was used near the Pelton wheel, but that the pipe was always allowed to run free. Even then, if any allowance were given for corrosion, the metal seemed light, and it would be interesting to know if the results were in every way satisfactory.

With reference to the question of gold-saving, a little more information as to the yield of gold per ton of gravel and its general size would be interesting. It appeared to him that the method of handling the gravel might have been modified. It was one thing to move a large quantity of spoil with a dredge for deepening channels and the like, and another to treat the spoil dredged up efficiently for saving gold. The tendency at present was generally to treat

smaller quantities of ground with a high rate of extraction, but the Author's practice seemed to be rather in the reverse direction. A bucket-dredger was not always suitable for this class of work, as it was not well adapted for getting into the hollows and corners of a rocky stream-bed, where most of the gold would probably accumulate; and it appeared to him questionable whether any such quantity of gravel as 90 cubic yards, or say tons, per hour could be treated economically with the apparently somewhat crude means for recovery at hand. These 90 tons were first passed through bars ¼ inch apart, and any gravel or gold not passing through went over the side. That would consist of any large nuggets, and say, 20 tons to 25 tons of gravel. The remaining 65 tons to 70 tons passed down the shoot over baize-covered tables. Such a quantity as 65 tons of gravel per hour must be very severe on the baize; and with 2,000 gallons of water per minute going with it very little fine gold could possibly be left behind. He thought that if the bucket-dredge were dispensed with, and the suction-pipe of the pump carried down to the bed of the river, quite as much gravel as could be fairly treated could be brought up, while a thoroughly good separating-plant, which would extract all the gold from the dredgings, might be adopted, giving probably an increased yield of gold. He would like to have more information as to these points, while he fully appreciated the very neat application of natural hydraulic power that had been carried out. Mr. Lockhart.

Mr. ROBERTSON, in reply to Mr. Gillott, said most of the points referred to had been carefully considered in the design of the plant, and the methods adopted had been selected for the following reasons: The position E, Fig. 1, Plate 2, for the motor had been selected in order to give the length between E and F for making up loaded trains for the main- and tail steam-haulage to the pit bottom, and for receiving the long trains of empty hutches for distribution to the several outlying points, H, K and L. These operations could not have been so conveniently carried out if the motor had been placed at F as suggested. The main- and tail-rope haulage was extended to the point F and overlapped the endless-rope electrical haulage system by the length E to F to enable the interchange of hutches to be conveniently carried out. Mr. Robertson

The system of running one continuous endless-rope through several branches had been in use at Earnock Colliery for many years, and had given great satisfaction. In cases where the hutches were connected to the rope singly, and without an attendant, it might be advantageous to be able to disconnect any branch line from the main line so as to have the means of throwing the

Mr. Robertson. branch line off in the event of wagons getting off the road, and so avoid stopping the whole system. Under the conditions obtaining at Earnock Colliery, that was with the hutches conveyed in short trains, with an attendant with each train, there was not the same necessity for disconnecting the branch roads, and it was considered an unnecessary complication causing increased friction. In the event of a train getting derailed, the clutch catching the rope was at once thrown off, and the hutches put on the rails as a rule without any difficulty, and without stopping the rope. The roads in these sections were kept in good order, and it was a rare occurrence for either a full or an empty hutch to leave the rails.

The Westinghouse engines in this installation were governed automatically, and gave uniform speed notwithstanding the great changes of load which took place, provided the changes were kept within the power of the engines. The vibration of the motor-gearing appeared at first to cause some little trouble with the insulation of the magnet coils, but after these coils had been fixed more securely this had disappeared, and there had been no trouble with the insulation of the armatures due to vibration. Various sizes of drums and pulleys from 3 feet 6 inches to 6 feet diameter had been in use in Earnock Colliery for endless ropes, and it had been found in practice that there was little difference in the wear of the ropes due to the various sizes of pulleys, and the smaller size of pulley had been adopted to save an unnecessary amount of reducing gear. The same rope speed had also been in use for many years, and had been found to give every satisfaction, and no difficulty was experienced in attaching the trains of hutches while the rope was in motion. In the case of the steam endless-rope in the main coal section between M and Q, Fig 1, the rope ran at about 4 miles an hour, and had a maximum gradient of 1 in 12 against the load. Trains of eighteen hutches were attached and detached while the rope was in motion, and the output on this rope was between 500 tons and 600 tons per day of one shift. The system adopted at Earnock colliery of running the hutches in trains, frequently left the rope free of load, but the motor driver could see from the ampere-meter when all the load was off, and as a rule the rope was stopped until he received the bell signal to re-start it.

The results obtained at Earnock for the power required to drive the light rope appeared to be better than those obtained at Messrs. Locke & Co.'s colliery. From various tests it had been found that between 0·41 and 0·62 lb. per yard of rope was required to maintain a uniform speed of 3 miles per hour; that was, with $\frac{3}{4}$ inch

diameter steel rope approximately between 350 lbs. and a little over 500 lbs. per ton of rope. Whenever they were required, back clips of a special form were used to prevent the hutches over-running the clip in front. He regretted to be unable to supply an estimate of the cost of doing the same work by steam or compressed air, but as he had already stated, it would be impossible to convey steam to the points where the power was used at Earnock, and the only other system which could be adopted economically would be compressed air. Mr. Robertso

In reply to Mr. Snell, the load on the motors varied greatly, as ropes with considerable loads attached were frequently thrown on and off by means of the friction-clutches. With regard to the conductors, the situation of those underground was perfectly dry, whereas in the shafts they were exposed to a considerable amount of moisture due to condensed steam, &c., and this had been the reason why the better insulation had been used in the latter position.

Mr. HAY, in reply, stated that the pipe-line consisted of 970 feet of 15-inch, 300 feet of 13-inch, and 50 feet of 18-inch pipes. On account principally of the large boulders encountered, the output of the dredge varied between its maximum capacity and about one-half of that quantity. The boulders precluded the use of a suction-dredge, and he had found bucket-dredges under ordinary circumstances more economical. The amount of gold raised weekly had varied between 70 ozs. and 10 ozs.—of a value of £3 18s. per oz. With regard to the efficiency of the Pelton wheel, the horse-power stated (88) was that computed from the pressure at the nozzle and the consumption of water, about 61 HP. being actually developed by the wheel. Mr. Hay.

12 March, 1895.

SIR DOUGLAS FOX, Vice-President,
in the Chair.

(Paper No. 2781.)

"The Kidderpur Docks, Calcutta."

By WILLIAM DUFF BRUCE, M. Inst. C.E.

THE Port of Calcutta is situated about 90 miles from the sea on the River Hooghly, which is formed by two branches of the Ganges, the Bhagirathi and the Jalangi, meeting at Nuddea. About 20 miles lower down than this town, a third off-shoot from the Ganges, the Matabhanga, falls into the Hooghly, and below Calcutta the Hooghly is joined also by the Damodar and Rupnarayan. Within the limits of that section of the river known as the Port of Calcutta, the Hooghly varies in width between 1,300 feet and 2,000 feet. At the point where it is joined by the Damodar it is about 5,000 feet wide, and from Diamond Harbour, 40 miles below Calcutta, it gradually opens out into an estuary, which at Saugor lighthouse is 15 miles wide.[1]

Tidal influence, when not checked by freshets during the rains, extends as far as Nuddea. From March to July, when strong southerly winds prevail, the current at spring tides during the early portion of the flood attains a velocity of 5 to 6 miles an hour. During the rainy season, when the discharge of fresh water by the branches from the Ganges is considerable, the down-stream current during the ebb-tide runs at about the same rate; and during heavy freshets in the river, the upward current at the flood-tide is hardly perceptible, although the level of the water is raised for many miles above Calcutta. At neap tides there is no up-stream current at all if there are freshets; the water is headed up and the level rises, but the current is always down-stream. This necessitated an arrangement of dock entrances to permit of vessels entering or leaving on the flood-tide, and

[1] Minutes of Proceedings Inst. C.E., vol. xxi. p. 2.

when the current in the river was continuously down-stream, as frequently happens during the rainy season.

The rise and fall of the tide at Calcutta is recorded by a gauge at the Kidderpur dockyard, the zero of which is 6·25 feet below mean sea-level. During the rains, the spring tides rise to a mean height of 20 feet 6 inches, and fall to 8 feet 6 inches above zero (datum), while neap tides rise to 15 feet and fall to about 10 feet above datum. In the dry season, which lasts from November to June, the spring tides rise to an average height of 15 feet, and fall to 2½ feet; while neap tides rise on an average to 12 feet and fall to 5 feet above datum. The tidal range between low-water of spring tides in the dry season and the average high water in the rainy season is about 18 feet, but during heavy floods has been as much as 22 feet 6 inches. During the dry season, the water in the river contains very little silt, but in the rainy season the quantity of solid matter in suspension averages 1 cubic inch to a cubic foot of water, and in heavy floods it contains three times that quantity. To meet this condition, special arrangements, to be hereafter described, were made to allow the mud to deposit before the water enters the docks.

The trade of the port, previous to the construction of the docks, was carried on at a wharf constructed on iron piles and extending for a distance of about 3,000 feet along the river bank, in front of the mercantile portion of the town. Eight jetties originally built were gradually lengthened and ultimately connected to form the present wharf with eight berths, which is still known as the jetties. It is equipped with hydraulic cranes, and sheds having an area of about 250,000 square feet. In 1870, when the Port Trust was established, only four jetties had been constructed, the remainder having been added between that year and 1880. Further extension of these jetties could not be made without encroaching on the river frontage of Fort William and the Maidan, which forms the park and recreation ground of Calcutta, but increased accommodation was required for the shipping. After investigation, a Committee, consisting of members of the Port Trust and of the Chamber of Commerce, recommended the construction of the docks as designed by the Author.

In selecting the Calcutta side of the river for the docks, the Author had in view the probable necessity of a ship-canal to the river Mutlah, as, owing to the constant changes in the navigable channels of the Hooghly, the navigation of that river might become impracticable. A canal to the Mutlah would be merely

an extension of the docks, and the heavy cost of lock-entrances to such a canal from the Hooghly would therefore be saved.

Kidderpur was the nearest point to the mercantile part of the city at which ground could be obtained at a reasonable cost, the Committee considered that the docks would there be within easy distance of the merchants' offices and warehouses, and that no inconvenience would result from the transfer of business from the river and jetties to the docks, particularly as the East Indian Railway would be placed in direct communication with the docks by the Jubilee Bridge at Hooghly, then under construction, and since completed.

The general arrangement of the docks is shown in Fig. 1, Plate 3. The length of dock No. 1, measured along the centre line, is 2,600 feet, and its width for the greater part of its length is 600 feet. It has an area of 34½ acres. The original design provided for an extension on the site shown for dock No. 2, and all necessary arrangements have been made for proceeding with this extension when required. The entrance to the docks is through a tidal basin 600 feet by 680 feet, and from the river to this basin there are two entrances; one consisting of a lock 60 feet wide and 400 feet long between the gates, Figs. 2, and the other an entrance 80 feet wide fitted with a single pair of gates, Figs. 3. The outer sills are in each case 17 feet below datum, and during the dry season the depth is never less than 19 feet 6 inches over the sills at low-water of spring tides. During neap tides in the dry season there is 26 feet, and during spring tides 32 feet of water, over the sills at high-water.

The site of the entrances is probably the best that could be obtained within the limits of the port. There are no eddies along the bank at this place, on either flood- or ebb-tides, and there is a good anchorage immediately above it. The bend in the river also allowed of the entrances being placed at such an angle to the bank, as greatly to facilitate the entrance and exit of vessels. Ships docked before high-water anchor above the upper entrance which points up-stream, and when the gates can be opened are breasted in alongside the jetty head and hauled into the tidal basin. This arrangement answers well in practice, and no difficulty has been found in taking vessels in or out by this entrance during flood-tide. The entrance to the 80-foot gates has not yet been dredged to the full depth. It stands nearly at right-angles to the 60-foot entrance and points down-stream. It is intended for the use of vessels which cannot arrive before

high-water so as to enter the dock by the upper entrance, and it will also be required during freshets in the rainy season when the current in the river is always down-stream, and it is inadvisable to use the upper entrance which faces directly up-stream.

Between the tidal basin and the dock there are two entrances, Figs. 4, one of which is 60 feet and the other 80 feet wide. One entrance would probably have been sufficient, but it was considered advisable to make a double entrance, as an accident to a single pair of gates would have rendered the docks, for a time, useless. The sill-levels at these entrances are 12 feet below datum.

On the east side of the tidal basin a large graving-dock has been constructed. It is 520 feet long with an entrance 70 feet wide. The depth from the coping to the top of the sill, which corresponds with the top of the blocks, is 27 feet 6 inches; and as, by opening the sluices between the dock and the tidal basin, any required depth of water can be obtained, vessels can enter or leave the dry dock at any time. At the north-east corner a smaller graving-dock has been constructed for the use of vessels of the Indian Marine. It is 350 feet long with a 60-foot entrance, and is 26 feet deep from the sill to the coping. As the height of water can be regulated in the manner above described, it possesses the same facilities as the other dock for docking or undocking at any time. The entrances to both docks are closed by caissons of the design shown in Figs. 5, 6 and 7, Plate 3. These caissons are constructed of wrought-iron throughout, with greenheart meeting-faces. The pumping-engines are placed at the north-east corner of the tidal basin, between the entrances to the two docks, and are so arranged that water can be pumped from either or both at the same time. The machinery, which was supplied by Messrs. J. and H. Gwynne, consists of two centrifugal pumps with 33-inch suction- and delivery-pipes, each worked by a high-pressure steam-engine having a cylinder 22 inches in diameter and a stroke of 24 inches. When working together the two pumps are capable of emptying the larger dock, with no vessel in it, in two and a half hours. A smaller centrifugal pump is also provided for pumping leakage-water from the docks. Steam is supplied for these engines by three Lancashire boilers, each 30 feet long by 7 feet in diameter, working at a pressure of 80 lbs. per square inch. The following is a statement of the performance of the pumps at a trial made with no vessel in the docks :—

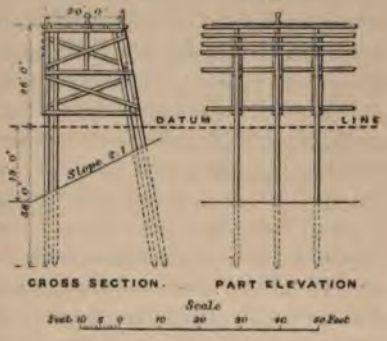
—	Port Commissioners' Dock.	Government Dock.
Volume of water at 20·5 feet level	Cubic Feet. 938,100	Cubic Feet. 495,315
Time required for emptying with one pump . . .	Hrs. Mins. 4 30	Hrs. Mins. 2 50
Discharge per second	Cubic Feet. 57·9	Cubic Feet. 48·56
Time required for emptying with two pumps . . .	Hrs. Mins. 2 10	Hr. Mins. 1 30
Discharge per second	Cubic Feet. 104·2	Cubic Feet. 91·72

The gates for the lock and the other entrances, Figs. 10, 11, 12 and 13, Plate 3, were constructed by Messrs. Sir W. G. Armstrong, Mitchell & Co. The heel-posts, meeting-posts and sill-pieces were sent out completely riveted, so as to reduce as far as possible the work to be done in India. This method, though entailing a larger cost for freight, was more satisfactory than performing such important work by native labour. The gates are worked by hydraulic cylinders fitted with plungers and multiplying sheaves placed horizontally beside the recesses for the gates, pressure being supplied at 700 lbs. per square inch from the engines at the south end of the dock. To provide for any difficulty that might arise from settlement in the roller-paths, the gates were designed to have great buoyancy, and the total weight on each roller of the largest pair of gates, with 25½ feet of water on the sill, is only 5½ tons. The anchorage has also been made sufficiently strong to carry the gates, if necessary, without assistance from the rollers. The gates are constructed of wrought-iron with greenheart heel- and mitre-posts. In every case stops have been formed on each side of the gates, to enable caissons to be put in these positions should the dock-gates or chambers require repair. It was intended that two caissons for the 60-foot entrances and two for the 80-foot entrances should be supplied, but only one caisson for each entrance has so far been constructed. Details of the caissons are shown in Figs. 14, 15 and 16, Plate 3. They have been made specially for the outer ends of the river-entrances, but may of course be used at the inner stops also. They were considered necessary to protect the outer gates from damage by heavy waves during cyclones.

Timber jetties, *Figs. 17* and *18*, are constructed in the river to form approaches to the 60-foot lock and the 80-foot entrance. The piles of these jetties are of greenheart, between 13 inches and 16 inches square, and between 45 feet and 65 feet in length. The

bracing, fenders and deck-timber are of teak. No cofferdam was used in building the river end of the 60-foot lock and 80-foot entrance, a sufficient bank of earth being left between the masonry and the river to keep out the water until the completion of the works, when the bank was cut away and the entrance dredged out.

Fig. 17. *Fig. 18.*



An objection was raised to the construction of docks in Calcutta on the ground that if fed entirely from the river by water entering through the locks, it would be impossible to entirely change the water, which in time would become foul and deleterious to health. To meet this objection and also to prevent the entrance of water heavily charged with mud, it was necessary to have arrangements by which the whole of the water in the dock would be regularly changed; and the Author decided to make the normal level of the water in the docks above the level of high water in the river, and to make up by pumping the loss caused by lockage and flushing.

The objects which the Author had in view were therefore:—(A) To keep the water higher than the level of high-water in the river, so as to prevent the influx of water direct from the Hooghly into the docks; (B) to allow the water before being pumped into the docks to settle and to deposit all the mud held in suspension before the water reached the pumping-engines; and (C) to keep the dock-walls as high as possible, and to avoid carrying their foundations deeper than was absolutely necessary. To meet these requirements a canal connecting the docks with Tolly's Nullah was constructed in which water is allowed to deposit its mud before being pumped into the docks. This canal, which is also used for the boat traffic between Tolly's Nullah and the docks, is 3,300 yards in length from the main pumping-station to the lock and sluices through which the water is drawn. At high-water these sluices are opened and the water is allowed to flow into the canal until its level attains that of high-water. The sluices are then closed, and as the flow of water through the canal is very slow, the mud which it contains on entering through the sluices, is deposited before reaching the pumping-station. It has been found in practice that the whole of the mud is deposited within the first 1,000 yards.

By this arrangement, dredging will be almost entirely restricted to the first half mile or so of the canal, where the cost of doing the work will be much less than in the docks, and the inconvenience of having dredgers working in the docks will thus to a great extent be avoided. In the original scheme, the Author proposed that Tolly's Nullah should be locked close to the point where it enters the Hooghly; and, if this had been done, greater facilities would have been provided for the boat traffic from Eastern Bengal. The arrangement of the pumping-engines and culverts at the main pumping-station where all the water is pumped into the docks is shown in Figs. 8 and 9, Plate 3. It will be seen that there are three centrifugal pumps having suction-pipes 36 inches in diameter, each pump being worked by a horizontal compound jet condensing-engine, with cylinders 13 inches and 24 inches in diameter, with a stroke of 24 inches, steam being supplied by four Lancashire boilers each 7 feet in diameter and 28 feet long. The working pressure is 80 lbs. per square inch. Each pump was constructed to raise 250,000 cubic feet of water per hour through a height of 10 feet; and at a preliminary trial the pumps raised 233,000 cubic feet through a height of 11 feet in one hour, which would be equivalent to about 256,000 cubic feet raised through a height of 10 feet.

The docks have been equipped with fifty-six movable hydraulic cranes of the design shown in Figs. 19 and 20, Plate 4. These cranes were constructed by Messrs. Sir W. G. Armstrong, Mitchell & Co. Fifty of the cranes are constructed to lift 35 cwt., and six have been made with double cylinders—the smaller to raise 35 cwt., and the larger to raise 5 tons. Each of the cranes has a rake of 36 feet and overhangs the quay 29 feet. The pressure-pipes are laid in culverts constructed in the dock-wall immediately below the cranes; and provision for connecting the cranes with these mains has been made at intervals of 13 feet 4 inches, as shown in Figs. 19 and 20. The distance between the wheels on which the cranes travel is 10 feet, the outer wheel, or that nearer the face of the quay, being carried on an 80-lb. bridge-rail and has two flanges; the inner wheel has no flange and works on a cast-iron plate let in flush with the coping-stone. This arrangement was adopted to avoid the inconvenience sometimes caused by an inner rail raised above the quay obstructing the free movement of the lower end of gangways, as vessels rise and fall in the dock. The docks have also been supplied with six 11-ton capstans and five 5-ton capstans for working the traffic at the entrances. These capstans, as well as the machinery for

opening and closing the gates, and that for the sluices and the bridges across the entrances, are worked by hydraulic power. The engines which supply this power are placed at the south end of dock No. 1. The machinery, Fig. 21, Plate 4, consists of two compound condensing-engines of 230 I.HP. each; the cylinders of which are $19\frac{3}{4}$ inches and 37 inches in diameter respectively, with a stroke of 38 inches. The accumulator is 20 inches in diameter, has a stroke of 35 feet, and is loaded to a pressure of 700 lbs. per square inch. The force-pumps are double-acting, with plungers $7\frac{3}{4}$ inches in diameter, driven direct from the piston-rod of the steam-cylinders. These engines are supplied with steam by four Lancashire boilers each 7 feet 6 inches in diameter and 30 feet long. They are fitted with automatic stoking apparatus, the coal being raised in trucks by a small hydraulic lift to a line of rails on which the trucks can be carried directly over the hoppers where the coal is dropped through the bottom of the truck. The working-pressure in these boilers is 85 lbs. per square inch. The pressure-mains are carried round the docks in the subway shown on the section of the walls. At the entrances, where subways could not be built clear of the machine-pits, sluices, &c., the pipes are carried in a small chase close to the surface, and are covered with iron plates. By this arrangement, the whole of the hydraulic piping can be examined at any time without the necessity for opening the ground behind the quay walls.

In addition to the cranes described, a pair of sheer-legs capable of lifting 100 tons has been erected on the east wall of the dock. It is worked by steam-power, which is supplied from an independent boiler close to the engines. The sheer-legs, as well as the engines and machinery for working them, were constructed by Messrs. Day, Summers & Co. The front legs are 130 feet long and the back leg is 170 feet long. The overhang of the sheer-head is 40 feet and the in-hang 9 feet from the face of the quay-wall. The upper blocks are fitted with seven sheaves, five for the main purchase and two for the light purchase. The main purchase bottom-block is fitted with four sheaves, and a single bottom-block is provided for lifts of less than 30 tons. There are nine parts of 5-inch steel-wire rope for the main purchase, each having a breaking stress of 64 tons, and the light purchase has three parts of a similar steel-rope. There are two hoisting-winches for the main purchase, and one for lifts of under 30 tons. The main purchase, which is driven by spur-and-worm gearing, has a grooved barrel of sufficient length and diameter to give a hoisting range of 80 feet. The light-purchase winch is of similar construction, but

has a barrel of sufficient length and diameter to give a hoisting-range of 125 feet. The legs can be run in or out whilst the load is being raised or lowered. The bed-plate is of cast-iron with wrought-iron plates carrying the traversing screw, and is held down by wrought-iron bolts to the concrete foundation. The engines working the sheer-legs have cylinders 15 inches in diameter with a 15-inch stroke, and are supplied with steam from a horizontal tubular boiler 7 feet in diameter by 12 feet in length.

Cargo-sheds have been constructed on both sides of the dock, each shed being 300 feet long and 120 feet wide. They are constructed in two bays of 60 feet each, carried on cast-iron columns of H section, and are roofed with corrugated iron, and they are enclosed by 15-inch brick walls built between the H columns, and are fitted with sliding doors, one in each 15-foot bay. To avoid down-pipes passing through the sheds to drainage channels under the floors, the centre gutters were made large enough to carry the rain-water to the ends of the buildings, the necessary fall being obtained by raising the bases of the middle columns. All the gutters are of $\frac{1}{8}$-inch galvanized-steel plates. The floors are laid with a slope of 1 in 60, and on the quay side are raised one foot above the coping-level. The height above ground-level at the back of the shed is 3 feet 6 inches, and along this inner face a platform 8 feet wide has been constructed for the convenience of the railway traffic. The total shed-area provided is 432,000 square feet, in addition to which space has been allowed for the construction of large warehouses in close proximity to the docks and in direct communication with the railway system.

The arrangement of the railway lines—which are all of 5-foot 6-inch gauge—is shown in Fig. 1, Plate 3. In all, about 28 miles of line, in addition to that required for the changing station, have been laid. A line of rails has also been laid along the river bank to connect the present wharves and jetties with the docks. A swing-bridge, Figs. 22, 23, and 24, Plate 4, adapted for rail and cart traffic, is provided across the double entrance between the basin and the dock. This bridge, which spans the two openings, is 220 feet in length, and has a clear width of 23 feet 9 inches. It is mounted on live rollers, and is worked by hydraulic power, being entirely under the control of one man stationed in a box at the end of the bridge, Fig. 23. Over the passage, which has been constructed at the end of dock No. 1 to form the connection with any extensions which may hereafter be made on the space provided for a second dock, a double-leaf swing-bridge has been erected. Another small swing-bridge,

worked by hand-power, carries a line of railway over the canal to the docks near the main pumping-station. Three other girder bridges, each of 100 feet span, have been provided to take the road traffic over the canal between Tolly's Nullah and the main pumping-station.

The whole of the quays and sheds are lighted by electricity. Arc-lamps of 2,000 candle-power, supported 20 feet above the ground, are carried on poles between each shed and at the entrances. Each of the sheds has forty 16 candle-power incandescent lamps hung from the tie-beams of the principals. In addition to these and the arc-lamps, a terminal-box is provided in each shed, to which a portable lamp may be connected, in case of more light being required in any part of the shed, or outside when loading or unloading has to be carried on at night. The engine-houses and offices are also lighted by incandescent lamps. The generating-plant consists of five Thomson-Houston arc-light dynamos, each machine driving twelve arc-lamps of 2,000 candle-power, and two Thomson-Houston alternate-current dynamos, each capable of supplying 550 incandescent lamps of 16 candle-power. The dynamos are driven by two pairs of engines, each pair having cylinders 13 inches in diameter and a 24-inch stroke, working a common crank-shaft carrying a fly-wheel, 12 feet 6 inches in diameter, grooved for rope-driving. This plant is placed in a building attached to the hydraulic-engine house, and the steam-pipes are arranged to take steam either from the boilers of the hydraulic engines or from those specially provided for the electrical plant.

The Dock-Walls.

The level of the site of the docks varied between 24 feet above datum close to the river and 19 feet above datum at the site of the main pumping-station; and, as all the land within the dock and railway enclosures had to be raised to a minimum height of 24 feet above datum in order to prevent flooding during high tides, a large portion of the spoil taken from the excavation for the docks and basin was used in raising the surrounding land to this level. Low-lying grounds around the docks were also bought before the work was commenced, and have been raised with the spoil. This raised land is now suitable for building purposes, and will become valuable when the docks are fully used and merchants require accommodation in close proximity to the wharves and railway. When the works were commenced, the excavated material was removed in ballast-wagons by locomotives,

but as the works proceeded and the inclines became steeper, a winding-engine was fixed on the ground taken up for the extension of the docks, and an incline was made through the 80-foot opening at the south end of the dock, up which the spoil was drawn.

The sections of the walls of the dock and basin, as designed by the Author and as constructed, are shown in Figs. 25, 26 and 27, Plate 2. The sections were not, however, determined without much discussion, and until actual trials of getting in the foundations had shown how the work might be best constructed. The opinions that were expressed by various engineers on the question of how these walls should be designed and founded are fully set forth in the "Report connected with the project for the construction of docks at Calcutta,"[1] a copy of which is in the library of the Institution. The borings, Figs. 28 and 29, Plate 4, showed that the walls would have to be founded in sandy clay, and when the first design was prepared it was anticipated that a considerable quantity of water would have to be dealt with in constructing these foundations. It was then proposed to found the walls on wells, but this was unnecessary, as the ground below a depth varying between 10 feet and 20 feet from the surface was found to be entirely free from water, but when slightly moist it resembled putty and behaved much like that substance when the pressure was removed from above it. The section of the cuttings in which it was first attempted to found the walls had side slopes of 2 to 1, and were carried down 10 feet below datum, the foundations being then built in a timbered trench carried down 22 feet below datum. The timbering of this trench had, however, only just been commenced when the sides of the excavation slipped, and the bottom of the cutting rose and destroyed the timbering that had been inserted. The Author then decided not to carry the open cuttings lower than 3 feet below datum, as it was found that at that level there was less tendency for the ground to rise, and the side slopes of the cuttings were thrown back to a slope of 3 to 1, as shown in Fig. 30, Plate 4. The section of the cutting then adopted was adhered to throughout the execution of the work. The lower portion of the wall is solid up to the level of the bottom of the dock, *i.e.* 10 feet above foundation-level. At this level the face of the wall, which has a batter of 1 in 24, is set back from the toe 3 feet, and is then carried up to the level of the subway by walls

[1] Selections from the Records of the Government of India, Public Works Department, Serials Nos. 4 and 9.

5 feet 10 inches thick at the face and 3 feet 9 inches thick at the back, joined by cross-walls 3 feet 4 inches thick at the top and 4 feet 2 inches thick at the bottom, spaced about 6 feet apart in the clear. The spaces were filled with broken bricks and, in some cases, with carefully packed layers of earth. The width of the wall at the top is 13 feet 9 inches, and of the subway in which the pipes are laid 6 feet by 6 feet. Although the level of the open cutting was 3 feet below datum, it was found impossible to excavate any considerable length of trench for the foundations without running the risk of the bottom of the trench rising. The Author consequently determined to found the wall in halves, and the chances of failure were further reduced by laying the brickwork in lengths of 12 feet 6 inches, Figs. 31 and 32. The excavations for the trench consisted therefore of a series of pits 12 feet 6 inches long by 17 feet 6 inches wide, sunk alternately, and when the brickwork in those first excavated was built up to within 12 feet of datum-level, which was the top of the solid portion of the wall, the intermediate pits were excavated and were similarly filled with brickwork. Above these foundation-pits, the brickwork was carried in a continuous timbered trench up to the berm-level. In the blocks of masonry built into the pits, the brickwork was toothed to bond with that of the intermediate pits as they were constructed. In this manner the whole of the work was carried out.

In excavating for the walls of the basin, the entrances and the graving-docks, where, on account of the confined area in which the work had to be carried out, large cuttings could not be made, the timbered trenches had to be begun at a higher level. The upper part of the excavation was taken out in open cutting from depths varying between 14 feet and 29 feet below the ground-level, which in this part of the work was about 25 feet above datum. The slopes of the open cuttings were made $1\frac{1}{2}$ to 1 from the surface to a depth 14 feet above datum, 3 to 1 from that level to 6 feet above datum, and thence 4 to 1 to the bottom of the cuttings, which in the deepest cases were carried to 1 foot below datum. From the bottom of the open cuttings the excavation was carried out in timbered trenches, the depth of which varied between 25 feet and 30 feet, and the width between 20 feet and 23 feet. Teak was used for the struts and walings and yellow pine for the polings, the timbering being generally executed in frames 16 feet in length with three struts to each, and set in the trenches at vertical distances of 3 feet 3 inches to 4 feet from centre to centre, according to the nature of the ground and the

requirements of the work. As soon as the foundation-level was reached in any part of a trench the brickwork was commenced, and at least 18 inches depth of brickwork was built before the work was left.

Although the section of the wall as constructed was decided on after the ground had been opened, and experience had been gained as to the slope at which it would stand, the Author was of opinion that, to render the walls perfectly safe during construction and until the water could be admitted, it would be advisable to leave a berm of earth in front, and to have no filling put behind the walls higher than the berm-level, until the dock was filled, when the berm could be dredged away and the wall backed up. It was pointed out during the discussion which took place on the dock-walls[1] that as the wall was of sufficient width at the top to entirely carry the hydraulic cranes with the pipes in the subway below, the erection of the cranes and the laying of the necessary hydraulic pipes could all be completed before the backing was carried up to the coping-level.

This method of construction, with the berm left in front and no backing higher than the berm-level, was adhered to until the works were almost completed; and when the Author visited the works in February, 1890, the walls were complete, and the backing was in this condition—subsequently, however, the backing was filled to within 2 feet 4 inches of coping-level. Early in October, 1890, when the walls had been built to their full height, but before the dock had been fully excavated, a movement was observed in the walls of the dock, an account of which, with a description of the remedial measures adopted, has been given to the Institution by Mr. J. H. Apjohn, the engineer then in charge of the work in India.[2]

The walls are of brickwork throughout, the mortar being made from ghooting lime and soorkhee (pounded bricks). The sills, hollow quoins, caisson-stops and sluice-frames are of granite, which was obtained from Cornwall dressed ready for setting. The coping is of Mirzapur stone. The works in India were executed entirely on what is known as the departmental system, petty contracts being given for the supply of material and labour. The total quantity of brickwork executed was 14,297,459 cubic feet containing 171,568,000 bricks; more than 2½ million cubic feet of ghooting lime were used with a similar amount of soorkhee.

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[1] *See* footnote p. 98, *ante*.

[2] "Note on the Movement of the Walls of the Kidderpur Docks," *post*, p. 104.

For dealing with this quantity of material in the confined space of the docks, it was considered advisable to lay the main lines of railway shown in Fig. 1, Plate 3, before any other work was begun. A line was also constructed from the docks to the Eastern Bengal Railway, by which the lime had to be brought from Raniganj; and, as the greater part of the bricks were manufactured at the Government brick-fields at Acra, a line of railway was also laid from the site of the docks to that place. These lines greatly facilitated the execution of the work, and on the completion of the docks they were sold to the Eastern Bengal State Railway, forming a branch of that line to Budge-Budge on the River Hooghly, where all kerosene-oil ships are now discharged. The cost of the work is given in Appendixes to the Paper.

From the commencement of the work in 1884 to April 1887, the Author had entire charge of the works, Mr. P. W. Soutter, Assoc. M. Inst. C.E., being the resident engineer on the dock division, and Mr. James S. Gaskell occupying a similar position on the tidal basin and river entrances. In April 1887, the Author left India on leave, and Mr. J. H. Apjohn, M.A., M. Inst. C.E., was appointed superintending engineer in charge of the works, the Author being at the same time appointed consulting engineer. The whole of the machinery, gates, caissons, &c., were constructed in England under the supervision of the Author, assisted by Mr. J. Angus, M. Inst. C.E.

The Paper is accompanied by numerous tracings from which Plates 3 and 4 have been prepared, and by two volumes of photographic views of the works.

APPENDIXES.

APPENDIX I.

STATEMENT OF THE COST OF THE DOCKS AND THEIR EQUIPMENT.

	Rupees.
Sixty-foot lock	18,42,451
Eighty-foot entrance to tidal basin	9,63,277
Tidal basin	16,89,524
Double entrance from basin to dock No. 1	14,57,516
Dock No. 1	60,12,235
Boat canal	10,95,348
Graving-dock	8,73,700
Embankment from Chandpal Ghat to Tolly's Nullah, and tramway from the jetties to the docks at Kidderpur	7,23,888
Pumping-engines for supplying docks	3,37,843
Removal and reconstruction of buildings in the Government dockyard	3,65,858
Cargo sheds	21,96,607
Foot-bridge across dock premises in line of Budge-Budge road	36,481
Swing-bridge across entrance to dock No. 2	1,29,701
Additional works for boat-canal	8,62,727
Government graving-dock	4,56,028
Electric lighting	1,80,746
Acquisition of land for dock No. 1	15,80,798
" " " "	10,00,190
Tools and plant	5,58,077
Establishment	8,35,741
Dredging	1,13,700
Repairs to walls	2,45,342
Changing station	2,20,000
Caissons for entrances	2,18,560
Interest during construction and discount on advances	37,43,573
	277,39,911

APPENDIX II.

STATEMENT SHOWING COST OF THE WALLS OF THE TIDAL BASIN AND THE DOCK.

Walls of the Tidal Basin (2,140 lineal feet; cost Rs. 12,80,476).

Description.	Quantity.	Rate.	Cost per Lineal Foot.
	Cub. Feet.		Rupees.
Excavation in open cutting . . .	4,520·00	Rs.24 per 1,000 cubic feet	108·48
„ „ timbered trenches . .	950·00	Rs.38 per 1,000 cubic feet	36·10
Brickwork, including pointing and filling voids	940·00	Rs.34 4a. 6p. per 100 cubic feet	322·24
Stonework	6·75	Rs.2 8a. per cubic foot	16·88
Steps, ladders, &c.	..	Rs.2 8a. per cubic foot	2·50
Timbering trenches	940·00	Rs.6 per 100 cubic feet	56·40
Pumping and petty items	940·00	R.1 per 100 cubic feet	9·40
Contingencies	..	Rs.8·33 per cent.	46·00
		Total . .	598·00

Dock Walls (6,435 lineal feet; cost Rs 29,22,934).

Description.	Quantity.	Rate.	Cost per Lineal Foot.
	Cub. Feet.		Rupees.
Excavation in open cutting . . .	3,150·00	Rs.24 per 1,000 cubic feet	75·60
„ „ timbered trenches . .	695·00	Rs.38 per 1,000 cubic feet	26·41
Brickwork, including pointing and filling voids	940·00	Rs.31 11a. per 100 cubic feet	297·90
Stonework	6·75	R.1 12a. per cubic foot	11·80
Steps, ladders, &c.	..	..	1·10
Timbering trenches	940·00	R.1 12a. per 100 cubic feet	16·45
Pumping and petty items	940·00	8a. per 100 cubic feet	4·70
Contingencies	..	Rs.4·37 per cent.	19·00
		Total . .	453·00

(*Paper No. 2669.*)

(*Abridged.*)

"Note on the Movement of the Walls of the Kidderpur Docks."

By JAMES HENRY APJOHN, M.A., M. Inst. C.E.

THE Author took charge of the construction of the Kidderpur Docks in April 1887, at which time open cuttings had been made for the greater part of the length of the walls to a depth of 3 feet below datum, *i.e.* 19 feet above the level at which the walls had to be founded. The only foundation work then built was a length of 200 feet by 25 feet, which required to be widened to 35 feet, the width of the section of wall finally adopted.

By the end of September 1890 the dock-walls had all been built, and the backing had been filled in most places almost to the coping-level, the bed of the dock being generally excavated to within 6 feet of the full depth, *i.e.* to 30 feet below the coping. A berm had been left against the walls 10 feet above this level, to be afterwards removed by dredging.[1] The Author considered that the carefully-rammed backing would not exert a greater thrust against the walls than that due to a natural slope of 3 to 1, although, during construction, the banks of the open cuttings had slipped to a much flatter slope, and he believed the berm sufficient to prevent movement.

Early in October the attention of the Author was called by the Resident Engineer to the fact that there seemed to be some movement of the backing which had been filled in behind the east wall to within 2·4 feet of the coping-level. This movement was indicated by cracks in the walls of the cargo-sheds which were in course of construction. The front walls of these sheds stood 50 feet from the edge of the coping, and the cracks in the end walls occurred generally about 70 feet from the coping. At the same time it was observed that the berm which had been

[1] See the description of the method adopted in constructing the walls, by Mr. W. Duff Bruce, *ante* pp. 97–100.

left against the walls presented a dry and cracked appearance. The Author was considering what steps should, under these alarming circumstances, be adopted, when, on the 7th October, the east wall began to bend out, and by the evening of the following day the coping-line had advanced nearly 6 feet at one place, the total length of wall along which the mischief was observed being about 1400 feet. On the morning of the 9th of October it was found that during the night the south-west wall had also been thrust out, the displacement extending over a length of 450 feet, and being at its maximum of about twice the amount observed on the eastern wall. Arrangements were at once made for filling the dock from the river, water from which was admitted on the 12th of October, and two days later it rose to within 10 feet of the coping, or 14 feet above datum, at which level it was kept until the completion of the works.

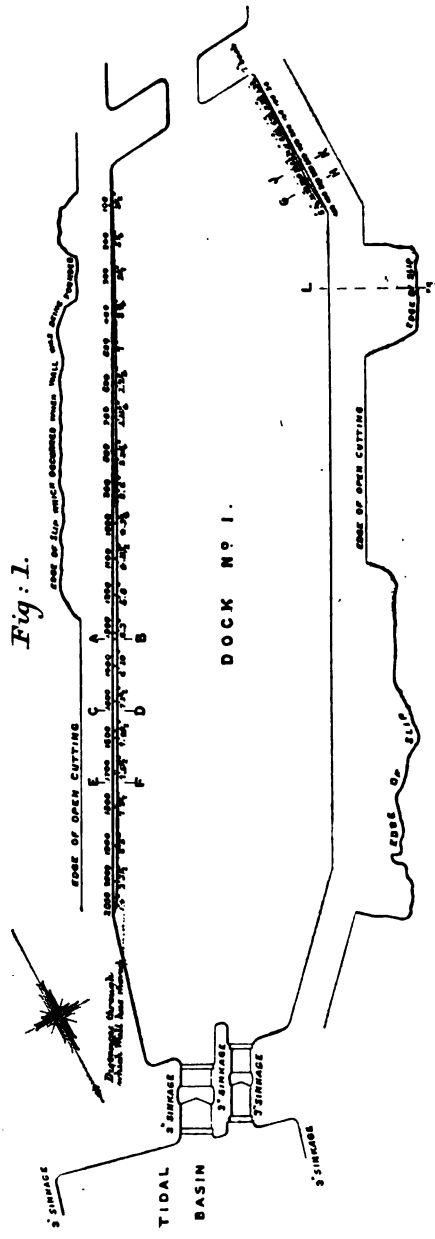
Between the time when the movement was first noticed and the filling of the dock the deflection of the eastern wall slightly increased, and the movement extended further to the southward, until it almost reached the south-east corner of the dock. The movement extended, *Fig. 1*, from the south-east corner to the shoulder 2,080 feet distant, the maximum deflection being at 380 feet from the shoulder. Southward from the place of maximum deflection, the line assumed by the coping was fairly straight. The maximum deflection here was 7 feet 5½ inches, and after the dock was filled no further movement occurred. The length of wall involved being great, the curvature of the face was slight, and consequently there were no cracks in it, except at the angle of the shoulder.

The state of the wall of the south-west berth after its movement is also shown in *Fig. 1*. Here the movement was much greater than at the opposite side of the dock, the coping being thrust forward at the place of maximum displacement 13 feet, and, the length of wall moved being only 450 feet, wide cracks appeared in the face.

The large scale plan, *Fig. 2*, shows the position and dimensions of the cracks which opened at the coping-level, and it also illustrates the remarkable fact that when the wall was pushed forward the portion 330 feet long between B and C acted as the long arm of a lever round the corner at C as a fulcrum, and actually thrust back the wall at D a distance of 7 inches, pulling the portion between C and F towards C a distance of 2½ inches, as shown by the cracks which have opened at E and F. The long arm of the lever from B to C is 330 feet in length, and from C to D

KIDDERPUR DOCKS, CALCUTTA.

Fig: 1.



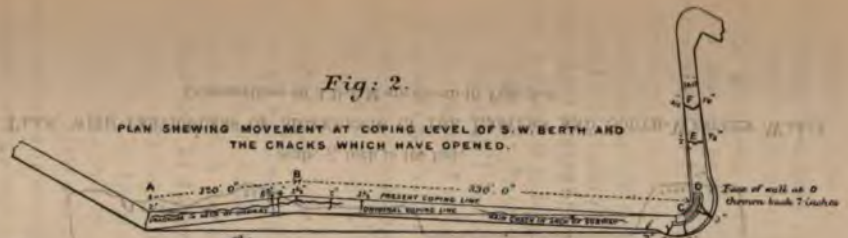
Scale, ¼ inch to 100 feet.

GENERAL PLAN, WITH PARTICULARS OF MOVEMENTS IN THE EASTERN AND SOUTH-WESTERN WALLS.

Cross-sections on A B–L M are shown in *Figs. 3–8.*

Fig: 2.

PLAN SHEWING MOVEMENT AT COPING LEVEL OF S.W. BERTH AND THE CRACKS WHICH HAVE OPENED.



GROSS SECTIONS OF WALLS.

Fig: 3

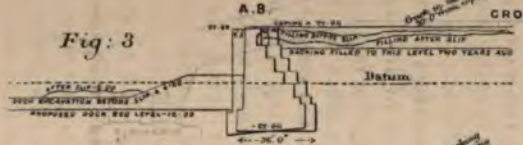


Fig: 4.

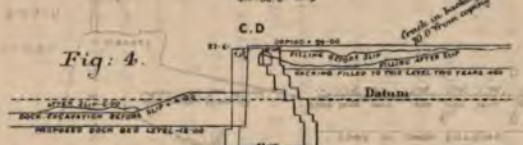


Fig: 5

Fig: 6

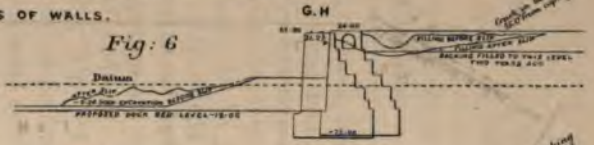


Fig: 7

Fig: 8.

N.B. The foundations were put in in two parts each 17' 6" thick.

This trench was timbered for a length of 200 feet, when the slip occurred. The struts were inserted into the walings about 9f. The walings were broken up and the runners shattered.

is 15 feet measured at right angles to the long arm. The arms of the lever are therefore in the ratio of 22 to 1. But the motion at one end has been 13 feet, or 156 inches, and at the other 7 inches, also in the ratio of 22 to 1. The fractures at E and F must have occurred before those at the corner.

With regard to the vertical movements of the walls of the cross-sections, before and after the displacements, *Figs. 3–7* show that the eastern and south-western walls behaved somewhat differently. In the former case, the wall was pressed forward gradually by the thrust exerted by the backing, and eventually came to rest when the resistances to its forward movement were equal to the pressure behind it. That this was the case is indicated by the tilting forward of the wall due to the sinking of its outer toe under the pressure thrown on it by the thrust of the backing. Further, the berm in front has not been much disturbed, but only to the extent that might be expected from the advance of the wall against it through a horizontal distance of about 5 feet. On the other hand, the south-west wall has not tilted forward, but still preserves the batter with which it was built, and the ground in front has been moved for a distance of about 85 feet. These facts seem to show that in this case the slip of the backing extended to a greater depth than the foundation of the wall, which was apparently carried out on the face of the slip.

In *Fig. 9* is shown the position of the eastern wall before the slip, the mean position of the three cross-sections after its occurrence, the levels to which the backing was filled in behind the wall, and the berm erected in front. The three forces to be considered are the thrust of the backing, the weight of the wall, and the thrust of the berm in front of it. The forces exerted by the filling behind the wall and by the berm in front of it, are to be considered by calculating their effect on the entire wall, and then compounding these forces with the weight of the wall.

The natural slope of the backing is an important consideration. In *Fig. 1* are shown the slips which occurred during the founding of the walls, the excavation being taken out with slopes of 3 to 1. Of the total length of these excavations 46 per cent. of the 3-to-1 banks slipped, and the profile of the greatest slip which occurred is shown in *Fig. 8* by the cross-section taken on L M. After the slip, the banks subsided to an average slope of $7\frac{1}{2}$ to 1. So it is but probable, that when the backing caused the movement of the walls, it was exerting a force due to a slope of $7\frac{1}{2}$ to 1, or in the case of the eastern wall (where the backing was 2·4 feet below the coping) 36·6 tons per foot of the wall. In

confirmation of the conjecture that the earth slipped to an inclination of $7\frac{1}{2}$ to 1 is the occurrence of the crack in the backing just before the movement was observed at a distance of 70 feet from the coping, or 39·5 feet from a vertical drawn from the back of the footings of the wall, the depth of which was 46 feet; hence—

$$\frac{39\cdot5}{46} = \tan \tfrac{1}{2} \text{ complement of angle of repose;}$$

$$\therefore \text{ angle of repose} = 8^\circ;$$

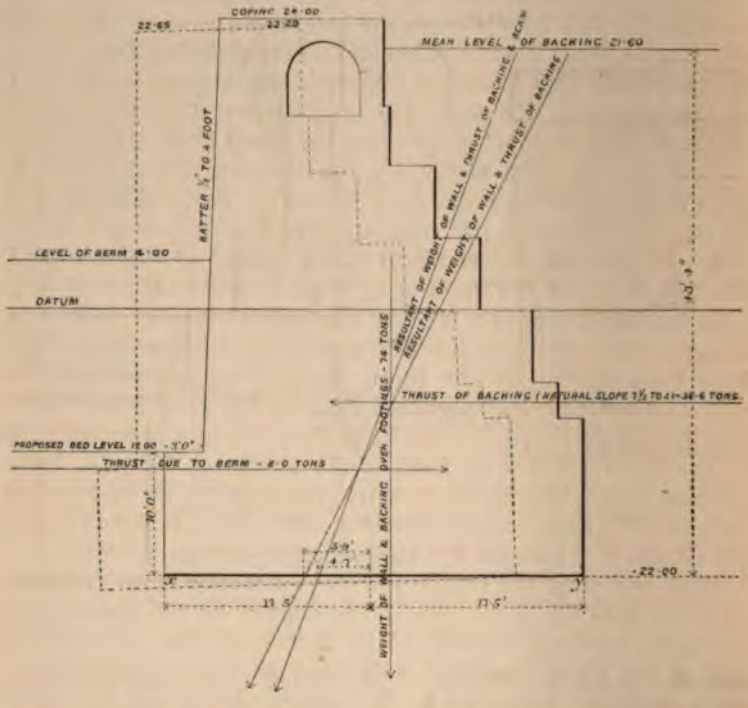
corresponding to a slope of $7\frac{1}{6}$ to 1.

To resist this thrust of 36·6 tons there was that due to the berm on the other side 26 feet above the bottom of the wall. Now the slope towards the dock of this berm was slightly less than 3 to 1, so it is evident that it cannot have been pushing against the wall at the time with the force due to a greater slope than 3 to 1, which would be equivalent to 8 tons per lineal foot. As has been explained, at the time of the slip the berm was dry and cracked, apparently shrinking away from the wall. So it probably was giving but little support, certainly less than 8 tons per lineal foot. If, therefore, the resultant of the weight of the wall, and the full thrust of the backing be found, it will be the maximum force tending to move the wall at the time of the slip; and if it be again compounded with the force of 8 tons which may possibly have been exerted by the berm, the minimum force operative will be obtained. This has been done in *Fig. 9*, with the result that in the first case the resultant cuts the base 5·9 feet, and in the latter 4·7 feet in front of the middle of the wall. The pressure exerted on the clay below the wall would, in the first case, be 4·2 tons per square foot at x, and nothing at y, and in the second case 3·7 tons and 0·5 ton per square foot respectively.

With regard to the stability of the walls after water had been admitted into the dock, the stress exerted by the pressure of the earth between the levels of the bottom of the wall and the bed of the dock, combined with that of the superincumbent water, will first be discussed. It has been shown that the earth in question is capable of exerting a thrust due to its liability to slip to $7\frac{1}{2}$ to 1; but, on the other hand, it is apparently at times quite inactive, as was the case with the berm left against the walls. However, it appears that with a considerable depth of water over it, the earth should be fairly constant in its action, with the hydrostatic pressure to keep it always pressing against the wall with more or less force. Now, if the backing slips at all, it certainly does not exert a less force than that due to a slope of

repose of 3 to 1, and it may, as shown above, be as much as that due to a slope of $7\frac{1}{2}$ to 1. But the pressure of water is equal to that of earth of the same depth having a weight of 112 lbs. per cubic foot and a natural slope of $3\frac{1}{2}$ to 1. It therefore seems probable that where earth stands against a wall, with water above the earth, the combined pressure of the two against the wall is not less than that which would be caused by a column of water of the whole depth. If this be admitted, examination of the

Fig. 9.

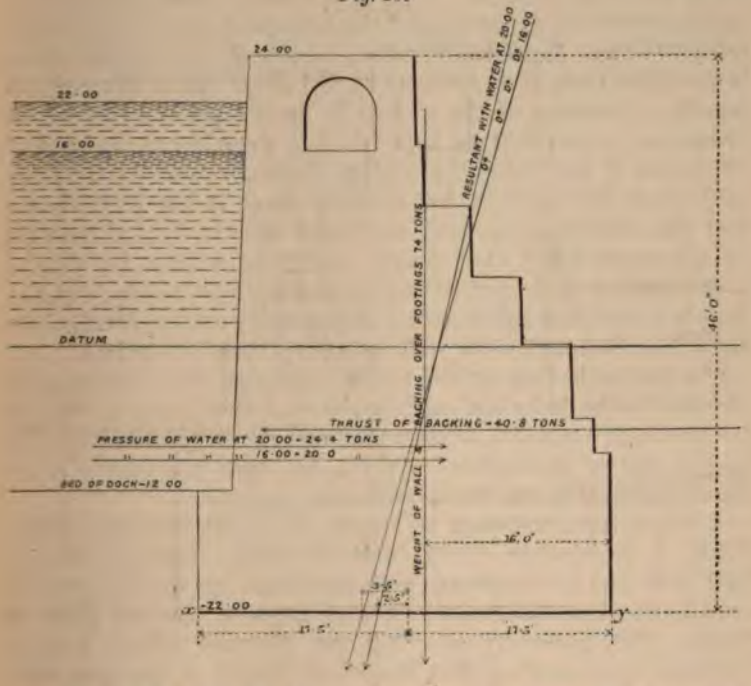

COPING 24·00
22·25
22·65
MEAN LEVEL OF BACKING 21·60
BATTER ½" TO A FOOT
LEVEL OF BERM 8·00
DATUM
RESULTANT OF WEIGHT OF WALL & THRUST OF BACKING
RESULTANT OF WEIGHT OF WALL & THRUST OF BACKING
THRUST OF BACKING (NATURAL SLOPE 7½ TO 1) 38·6 TONS
PROPOSED BED LEVEL 12·00 - 3'0"
THRUST DUE TO BERM - 8·0 TONS
WEIGHT OF WALL & BACKING OVER FOOTINGS - 74 TONS
22·00
17·5'
17·5'

conditions relative to the stability of the walls with water in the dock becomes extremely simple.

In *Fig. 10* is given a diagram showing the wall subject to the extreme case of the backing exerting a pressure of 40·8 tons per lineal foot, due to a slope of $7\frac{1}{2}$ to 1, under the condition of water being in the dock at the level of 16 feet above datum, and again of 20 feet above datum, a level which the Author considers should be adopted as the lowest to which the water shall ever be allowed

to fall. It may be seen that at these levels the support given to the wall is most material, the pressures being 24·4 tons and 20 tons respectively. For practical purposes, they may be considered opposite to the thrust of the backing, and either of them, together with the resistance of the wall to slipping due to its weight multiplied by the coefficient of friction, or, say, 25 tons, exceed the extreme pressure which the backing can exert. Consequently, there can be no danger of a slip forward. The pres-

Fig. 10.



sures at x and y, for heights of 16 feet and 20 feet, are 3·36 tons and 1·20 tons, and 3·00 tons and 1·20 tons respectively. The pressure of water has been taken as horizontal instead of normal to the wall. The difference is inappreciable; and in the most important case, where the wall has already moved, the face is now vertical. Under the extreme condition of the backing pushing against the wall with a force of 40·8 tons per lineal foot, the pressure on the toe of the wall would be considerable, and settlement would certainly occur; but, so long as the wall did not move forward, it would be of little consequence. The weight of goods-

sheds and their contents might possibly add about 5 tons per lineal foot to the thrust of the backing; but even so, with the level of water in the dock up to 20 feet above datum, there would be sufficient margin to ensure safety.

As the dock is supplied with water by pumping, the level to which the surface of the water in it may be allowed to fall is under control, and it has been determined to adopt 20 feet above datum or 4 feet below the coping as the minimum. When working the dock, the lowest level to which the tidal basin need be allowed to fall is 9 feet above datum. Its area is 10 acres, that of dock No. 1, together with the upper reach of the boat-canal and the boat-dock, being 60 acres. In order, therefore, to raise the level of the water in the tidal basin from 9 feet to 20 feet above datum as nearly as possible, a lowering of the surface in dock No. 1 of 2 feet would be necessary; and if it be kept raised by pumping to the level of 22 feet, or 2 feet below the coping, the water-level in the dock need never fall below 20 feet above datum. It has been shown that the relative amounts of earth and water in front of the wall do not much affect the thrust; so if the surface be always maintained at this level, it seems unnecessary to dredge out the dock-bed to 12 feet below datum as originally contemplated, since more than 26 feet of water will not at any time be required.

The Author, having arrived at the conclusion that the admission of water to the docks had entirely obviated the danger of further movement of the walls, advised that nothing should be attempted in the way of strengthening them, but that the coping lines should be straightened for the sake of appearance.

A Committee, consisting of Messrs. F. L. O'Callaghan, C.S.I., C.I.E., J. L. Mackay, C.I.E. (now Sir James Mackay), Horace Bell, and G. E. Ormiston, was appointed by Government to consider these recommendations, and reported on the 12th of March, 1891, generally adopting the Author's views, but in addition recommending that the whole length of the east wall which had moved should be bolted together by $2\frac{3}{4}$-inch through bolts at intervals of 10 feet, so as to hold together the two pieces into which the wall had been split by a longitudinal fracture.

The coping-line of the eastern wall was straightened by continuing the line of the moved wall from its southern end as a tangent to the curve of the bowed portion at the northern end, the tangential portion being corbelled out from the face. A length of 120 feet next to the north-east shoulder was carried back at an angle to meet the shoulder and was converted into landing-

steps. In the case of the south-west wall, which was badly split and cracked, the Committee recommended that the upper 10 feet should be dismantled and replaced by a solid bed of concrete, the portion from A to B, 120 feet long, *Fig.* 2, being converted into landing-steps, and the remaining portion, from B to C, 330 feet in length, having the coping worked to a straight line.

These repairs have been completed, and the berm has been dredged away without the occurrence of the slightest further movement of the walls.

The Paper is accompanied by drawings from which the *Figs.* in the text have been prepared.

Discussion.

Sir Douglas Fox.

Sir DOUGLAS FOX, Vice-President, was sure it would be the desire of the members to pass a hearty vote of thanks to the Authors. The Papers were valuable contributions to the Minutes of Proceedings. The first described an important work in itself, and also pointed out some difficulties which had occurred; the second fully detailed those difficulties. There was one class of information which it was specially desirable to have in the Minutes of Proceedings, namely, full particulars of difficulties encountered by members, and, when they gave them in such full detail, they deserved the hearty thanks of the Institution. His experience had shown that clay required most tender treatment. Engineers who had carried out large operations upon clay of a bad character had come to the conclusion, which was a very important one to be remembered, that some portions at any rate of the London clay, and also of that in the neighbourhood of Rugby and elsewhere, would not carry more than 2 tons to the square foot. That, after all, might be the cause of a great deal of the difficulty with which engineers had to contend when dealing with heavy walls upon a clay foundation. He was himself finding it necessary in heavy works upon the clay not to allow more than that apparently small load upon the foundation. It was desirable as far as possible in dealing with clay not to give the work any chance of slipping forward under the load at its back. The Papers were valuable, and calculated to open up wide fields of thought. He could not help thinking that the failures were to be ascribed to the fact that there had been movement upon a slippery surface below the level of the foot of the wall itself. This pointed to the importance, in a case of that kind, of not backing up the wall beyond the level of support of the berm until the water was in the dock.

Mr. Bruce.

Mr. W. D. BRUCE considered that as the story of the failure of the dock-walls had been told it would be well that the account should be complete. It had been stated by Mr. Apjohn that by the end of September 1890 the dock-walls had all been built, and the backing had been filled in, in most cases, almost to coping-level; that a berm had been left against the walls 20 feet below coping-level, and that he then considered the carefully rammed backing would not

exert a greater thrust against the walls than that due to a natural slope of 3 to 1: although during construction the banks of the open cuttings had slipped to a much flatter slope, he believed the berm sufficient to prevent movement. Mr. Bruce did not consider that statement fully explained the position. In February, 1890, when he had visited the works, the walls had been almost completed; the berm in front, up to the level of 20 feet from the coping, had been left, and no backing filled in higher than berm-level, above which the ground was sloped back at an inclination of 3 to 1. There had not then been the slightest sign of movement, and his attention had been specially drawn to that fact by the resident engineer. Subsequently the backing had been filled in to within 2 feet of coping-level, the greater part of that work being carried out during the rains, or between June and September, the four months immediately preceding that in which the slip had occurred. The wall, as he had already explained in the Paper, was continuous up to the berm-level, but above that gaps had been left in them at intervals, through which any water which lodged behind could escape. As the backing had been filled in those openings had been built up, and, as there were no weepers through the walls, there was no possibility of the escape of any water which lodged or drained on to the backing. The surface drainage had not been completed, and during the heavy tropical rains which immediately preceded the accident the water must have been soaking into the backing, or percolating down by the back of the wall, and saturating the foundations. That fact should be known to enable a true appreciation of what had led to the movement to be formed. No doubt many slips had occurred during the construction of the works, but only when the trenches had been excavated to a considerable depth below datum, and it would be more correct to describe the movements as settlements of the bank, with a spewing up of the excavations, than as ordinary slips. When the accident had occurred the whole of the trench had been filled in to a level of 4 feet above datum, and some conditions other than those which had caused the movements during the construction of the walls must therefore have been at work to cause the slip after the walls had been finished. Mr. Bruce.

Mr. Horace Bell stated that the first point which the Committee,[1] of which he had been a member, had found somewhat obscure, was that the east wall, in moving forward, had split vertically from one end to the other. The Committee had been unable to determine Mr. Bell.

[1] *Ante*, p. 112.

Mr. Bell. whether the fracture had any relation to the fact that the walls had been founded in two halves. Another point which probably Mr. Bruce might be able to explain, was that there had been no movement whatever in the west wall; it was absolutely uniform and plumb from one end to the other, and yet the two walls had been built in precisely the same way, of the same design, on the same soil, and were, for all practical purposes, identical. The failure of the walls had clearly been due to over-confidence, and if the backing and water-level had been brought up together, all would have gone well. The experience obtained during the founding of the walls had shown that the soil was of an exceptionally treacherous nature. He considered that Mr. Apjohn was right in the belief that the berm in front of the wall had availed little or nothing in preventing the initial movement.

Mr. Donaldson. Mr. H. F. DONALDSON thought that the possibility of water having penetrated into the base of the wall might to some extent account for the accident. He had in India, after a dry season, observed banks which had withstood perhaps one rainy season, but had not been grown over, run away almost like water immediately rain fell. He had noticed the action chiefly in the earth of a putty nature referred to in the first Paper, and particularly in white or bluish-white clay. In one case a cutting through such material had been trebled in size by water getting to it, the clay not being exposed until the cutting had been carried to some depth. He thought, however, that the form of the wall would more readily account for the accident if the base was horizontal, instead of being tilted back at the heel, so that there was nothing except its own weight to introduce friction as an element of safety in its stability. He would like to know whether there had been any reason for the wall having been founded on a level base. In filling the excavated space behind the wall, more particularly in damp or water-bearing strata, it would have been much safer to insert hand-packed rubble for a thickness proportionate to the height of the wall, so that if any water collected behind the wall, it was not subjected to any greater pressure than its natural head. Though the back of the wall by this means might always be wet, the pressure was materially reduced, and there was less risk of cracking or even of settlement. He had seen similar foundations in the same neighbourhood which had been treated in this manner, and others which had been filled in with rammed earth and clay; in the former case there had been no settlement or cracking whatever, while in the latter it had been, comparatively speaking, frequent.

Mr. Charles Colson remarked that a possible cause of the movement in the wall was that after the ground had been opened the lower strata, from exposure to the atmosphere and moisture, had become more or less plastic, and the weight of the backing placed on the top of the unstable material had compressed it, forcing it forward from beneath the wall. It reminded him of a similar case which some years ago had come under his notice. In that case a wall had been built on piles in clay, above which there were beds of stiff mud. Instead of the mud being taken out the backing had been filled on the top of it. The wall had remained straight and sound until some time after the backing had been inserted, when the wall had shown signs of forward movement without any valid cause. The foundations were known to be perfectly sound, and it was difficult to find the reason of the movement. The solution of the problem was probably that the weight of the backing on the soft mud had caused the latter to press out laterally, and so to push the wall forward. He thought action of the same kind had happened at Kidderpur, that the sandy clay had become soft and unstable after the water had reached it; and possibly the weight of the backing had caused deflection of the ground at the base of the wall in the line of least resistance, which would be towards the basin. This view appeared to be supported by the fact that in other parts of the basin, where the ground was probably of a more stable character, the wall, although constructed in a precisely similar manner, had shown no signs of movement. It was open to question whether, instead of making the walls cellular, it would not have been safer to have built them solid. He thought if the cells had been filled with material of the same description or with concrete, by giving more weight to the wall, with the base carried lower, the result would have been more satisfactory. No doubt there had been good reason for the method of construction adopted—probably to distribute the weight over as large an area as possible. Now that the water was in the basin the wall was said to be perfectly safe, but he thought there was risk in the walls depending for their stability entirely upon the pressure of water in front. Circumstances might occur which would necessitate the basin being pumped very low or even dry. He thought that there would be risk in lowering the water-level. Amongst other recorded instances of walls having moved in a similar manner and probably from the same cause—that was, defective ground at the back of and under the wall—might be mentioned the West India South-Dock wall, which had moved forward in

Mr. Colson.

Mr. Colson. 1868 on a fine silt joint or bed in the blue clay upon which the wall rested, and the East India Dock wall, which moved not only laterally but vertically, in consequence, it was supposed, of a bed of sand under the wall being affected by some excavations in connection with dock works about ¼ mile distant.[1] The walls of the Southampton Tidal Dock, founded on clay, had slipped forward in spite of every precaution in removing the mud at the rear and filling in the backing.[2] At the Avonmouth Dock trouble had been caused mainly by a treacherous bed of sandy clay, nearly as soft as silt, which had been found to lie between the bed of clay on which the wall was founded and the compact sand-beds beneath.[3] At Zug, in Switzerland, an extensive slip had taken place, in consequence of the unstable condition of the lower strata, which had been set in motion by the weight of the filling at the rear of the quay-wall and of the buildings placed upon it.[4] In none of these cases had the movement been due to deficient mass in the walls, but to unforeseen defects in the strata beneath the foundations. He asked whether, as it was considered necessary to use caissons for the outer entrances, the gates might not have been dispensed with. He would further suggest that the costs, instead of being given in rupees, should be given in pounds sterling if it were possible under existing conditions.

Mr. Duckham. Mr. F. E. DUCKHAM referred in high terms to the thoroughness with which the details of construction described in the first Paper had been thought out—such as the entrance having its direction up-stream, the adoption of simple rams instead of oscillating engines for opening and shutting the lock-gates, and the trapping of mud in the canal from which the dock was fed with comparatively clear water. It was questionable whether centrifugal pumps were better than scoop-wheels for lifting large quantities of water with a small lift, as for maintaining a higher level of water in a dock than in the adjacent river. He had used scoop-wheels with great success at Millwall, where 30,000 tons (over 1,000,000 cubic feet) of water were sometimes lifted into the dock in an hour. This was effected economically and with little wear and tear of machinery. He approved of steel-ropes for hoisting-tackle at the sheers, provided the sheaves were large enough. A chain for the purpose would have some 2,000 or 3,000

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[1] Royal Engineer Institute Papers, vol. iv. 1880, p. 15.

[2] *Engineering*, vol. l. p. 309, and *post*, pp. 125–127.

[3] Minutes of Proceedings Inst. C.E., vol. lv. p. 14.

[4] "Die Catastrophe von Zug." Verlag Von Hofer & Bürger. Zürich, 1888.

links, and the weld in every one of these would be a unit of danger. With reference to the batter of the dock-wall, when ships had been built like tubs, a battering wall conformed to some extent to the shape of the ship, but now that the cross-sections of ships were nearly rectangular the dock-walls should be vertical, and the upper 6 feet or 8 feet should be corbelled over so as to project a few inches beyond the lower masonry. The bilges of ships of the present day ground against battering walls, doing damage where it was least convenient to repair, and leaving gaps between the coping and the ship's side into which goods and persons were liable to fall. There were, he supposed, local reasons why the material of the wall had been brickwork instead of solid concrete. He had, some years ago, removed for repairs, from an 80-foot lock, a gate weighing 70 tons, which, being single-plated, had little support from the water. The roller had been removed by a diver, and the gate supported by blocks under the mitre-post ready for lifting by four Conservancy derrick-barges and removal into the dry-dock. There had been difficulty in getting the four barges into position, and to give more space one of them had lifted and moved the mitre-post off the blocks. The lifting purchase had suddenly given way and the gate dropped with a severe snatch upon the anchor-strap, but no damage had resulted. Evidently, therefore, unbalanced gates could be sustained by anchor-straps; but satisfactory provision would have to be made to reduce the friction and wear between the lower portion of the heel-post and hollow quoin; and obviously the more the strain on the anchor-straps was reduced by efficient lightness in construction or balancing the better. It would certainly be of great advantage to dispense with rollers and roller-paths, which produced a large portion of the work of opening and closing lock-gates. Mr. Duckham

Mr. JOHN GWYNNE stated that pumping machinery had been used extensively in raising the water-level in the docks of Liverpool and elsewhere, he believed with great success. The existing docks had, no doubt, suited the old ships; but, since the draught of vessels had increased so largely, it had become necessary either to deepen the docks by excavation or to raise the water-level by pumping. The subject had been dealt with by Mr. G. F. Lyster, Chief Engineer to the Mersey Docks and Harbour Board, who had made careful calculations, and found that it was more economical to pump water in than to put the docks out of commission and excavate them. That plan was now generally recognized, and many dock companies had adopted it both in Mr. Gwynne.

Mr. Gwynne. England and on the continent of Europe. The cost of filling the dock and raising the level of the water had not been found to be great.

Mr. Vernon-Harcourt. Mr. L. F. VERNON-HARCOURT thought it would be admitted that the sliding forward of the dock-walls was one of the most important points in the Papers. With regard to the foundations of the walls, he noticed that they rested upon blue clay. For many years he had considered blue clay the worst foundation for a dock-wall, for the reason that heavy weights slipped readily upon it when it came into contact with water. He should imagine that this accident would not have happened if the backing of the wall had not been filled in above the level of the berm in front. The interval left between the front of the timbered trench for the foundations, and the face of the dock-wall, owing to the stepping back of the wall at the dock-bottom had also contributed to the accident. In consequence, there had been a certain space between the berm and the face of the wall that had to be made up; and therefore the berm was not like solid ground against the wall. The berm had also become dry, and had actually shrunk away somewhat from the face of the wall. In all such cases, it was much easier to prevent the wall moving forward than to arrest any movement after it had commenced. One reason mentioned by Mr. Bruce for the wall moving forward, was that provision had not been made for the escape of drainage-water from the back of the wall, because constantly water accumulated behind dock-walls; and it was the regular practice to carry the drainage-water, from whatever source it might come, through the wall until the dock was ready to be filled with water. It appeared from the Papers that the actual slip pushing forward the dock-walls had, in one instance, occurred below the level of the wall itself. That had happened in a case within his experience twenty-seven years ago at the South West-India Dock, where the dock-wall had been founded in some portions upon blue clay. The wall had not slipped forward there; but natural concrete having been found a little above the level of the base of the wall as it would have been founded, it had been thought undesirable to take out the hard natural concrete, formed of gravel and shells that were found in the Thames basin, to insert fresh concrete. Eventually, in backing up that wall, a portion of it had moved forward, sliding, not of course upon the natural concrete, but upon a layer of the London clay below. In excavating for rebuilding that wall on lower foundations, two disconnected surfaces of clay had been found, one having slipped on the top of the other, showing that

Mr. Vernon-Harcourt.

the slip had actually taken place some distance below the bottom of the wall itself.[1] Since that occurrence, he had always considered blue clay the worst material on which to build a dock-wall. There were two entrances shown from the basin into the Kidderpur Dock. That seemed almost superfluous, but as a reason, Mr. Bruce had mentioned that one entrance might be out of repair. That was a consideration which might be urged in respect of all docks, and yet docks were frequently built which had to rely upon a single entrance. Moreover, as in this case caissons and recesses for them had been provided, in the event of any accident happening to the gates, one of the spare caissons might be placed across the entrance, and the dock worked in that way till the repairs could be completed. He was somewhat surprised to hear that it was necessary to place caissons in front of the river entrances to the dock, on account of the swell caused by cyclones. He would have thought that though the river was large, there could hardly have been enough swell to necessitate protection of the entrances by caissons, being, as they were, a long distance from the sea, and that the gates might have been strutted instead. He was aware that, at exposed sites, storm gates, opening in the reverse direction, were often provided, as for instance at Penarth, Grimsby, Dieppe, Ostend, and elsewhere; but considered that in a river so little exposed as the Hooghly such protection would hardly have been necessary. In order to provide against any settlement of the roller-path, Mr. Bruce had stated that the gates had been made specially buoyant, and supported strongly by anchor-straps. That naturally led to the suggestion that the rollers might have been dispensed with. It had been often a question whether or not it was desirable to have rollers for dock-gates. In some cases, as for instance at Dunkirk, where dock-gates had been placed across a 69-foot entrance, rollers had been dispensed with; and the plate-iron gates had been specially ballasted near to the heel-post, so as to throw as little weight as possible upon the mitre-ends of the gates. If there was any fear of settlement of the roller-path, it would seem better to dispense with rollers altogether. The method adopted by Mr. Bruce for supplying water to the dock free from silt was a good one. There were many docks in England and Wales opening into rivers where the water was very silty, as for example the Alexandra Dock at Hull, and the docks at Cardiff, Swansea, and Newport, where the water was pumped direct from clear freshwater supplies into the

[1] Minutes of Proceedings Inst. C.E., vol. xxxiv. p. 176; and vol. lxv. p. 189.

Mr. Vernon-Harcourt.

docks. At the Kidderpur Dock, however, there was no available supply of fresh, clean water; but fortunately the difference in the velocity of the current in the river, and in the canal, led to the deposition of the silt in the first portion of the canal, whence it could easily be removed without inconvenience to the shipping. If there had to be two entrances, a bridge spanning the two openings, and supported in the centre, was one of the most economical forms of swing-bridge that could be adopted. He asked, with regard to the river-entrances to the dock, why it had been considered desirable to have a lock in one case, and an entrance with one pair of gates in the other. He presumed that the level of the river was always fairly high, or in flood, when the entrance lower down was used, and that therefore, there was no difficulty in getting on a level with the basin, and it was not necessary to lock the vessels in; otherwise it would seem curious to have a lock in the one case and an entrance in the other. He assumed that the hollows in the dock-wall had been introduced for the sake of economy in a wall of such considerable width at the base. The section of the dock-wall, indeed, gave the impression that settlement in the alluvial soil was supposed to be the main danger to be guarded against, though the slips which had occurred in excavating the foundations had given warning of its treacherous nature; for a solid wall would have afforded considerably greater resistance to horizontal displacement. The building of the base of the wall on a slope, with the toe at a higher level than the back, would prevent the wall sliding forward horizontally on its foundations; but this arrangement would offer no additional security against slips in the clay below the base of the wall. The batter generally given to the face of dock-walls, objected to by Mr. Duckham as inconvenient in working, was due to a dock-wall being actually a high retaining-wall before the dock was filled; and, in reality, a considerably curved batter would be theoretically advisable. The omission of the batter would, in fact, necessitate further widening at the back towards the base, and consequently additional excavation and backing, as well as a less advantageous section. The adoption of vertical dock-walls might be expedient on account of the vertical sides of vessels of the present day; but he could not approve of an overhanging wall at the top, as suggested, for this would expose the thin upper part of the wall and the coping to the full shock of vessels coming against it.

Mr. Lewis.

Mr. W. B. Lewis mentioned, by way of contrast, the Brentford Dock, built by Mr. Brunel many years ago in blue clay. A different section from that shown in Figs. 25–27, Plate 4, had been

adopted, vertical walls or piers being at intervals arched over between at the top, and connected at the back by horizontal arches carried up with a good batter, so as to give as great a surface as possible. The base of these curved retaining-walls, instead of being flat was enlarged by footings and tilted. The result was a section that might be described as the reverse of that shown. Although that gave a vertical face for dock purposes, the stepping back was against the earth instead of against the water. He should be glad to know what weight per square foot there was on the foundation of the Kidderpur dock-wall. It would be interesting because he thought the ground there was very weak and would only stand a small pressure. He had listened with great interest to the Paper, having been many years ago concerned in a scheme for constructing docks in the same place. An objection had then been raised that it would be impossible to keep the water in a sanitary condition, and that it would become putrid on account of the climate.[1] He was glad to learn from the Papers that the difficulty had been overcome by the plan of keeping the water in the dock at a higher level than that in the river. Mr. Lewis.

Mr. E. BENEDICT asked whether any levels had been taken on the coping, and whether the wall had settled during the slips, or had slid on the level. Mr. Benedict.

Mr. W. SHELFORD, having carried out work in clay, knew something of its eccentricities. He had heard various explanations of the slipping of the dock-walls. It had been remarked that there had been a slip on the upper side, but on the opposite side, built in exactly the same manner, there had been no slip or movement. Engineers who had experience with clay knew that in London clay, and in every clay he had ever met with, there were greasy surfaces at various inclinations which caused slips. In more than one instance such a greasy surface had lain under the foundation of a work, which, however strongly built, had given way, sliding down in the direction of the greasy surface. The only way to prevent such an occurrence was to cut through the greasy stratum and to found below it. That, of course, would be a serious matter in the case of the Kidderpur dock. He ventured to suggest that the real cause of the slipping of the work had been something below the foundation with an inclination towards the bottom, the effect of which had been to make the upper wall bulge Mr. Shelford.

[1] Report of the Committee appointed to consider the probable effects of the proposed wet docks at Kidderpur upon the health of the neighbourhood and of Calcutta. Calcutta, 1885.

Mr. Shelford. and rather to sustain than to destroy the lower one, which had been built in exactly the same manner—that is, if the disturbance extended so far. He understood Mr. Bruce's intention had been to balance the pressure against the walls by regulating the level of the water inside, and the backing outside, the dock, and that the wall had not failed so long as that plan had been adhered to.

Mr. Walmisley. Mr. A. T. WALMISLEY mentioned, with regard to the importance of properly setting out a roller-path, that in the case of dock-gates at Dover, it had been found that the carriages which had been fixed prior to his appointment as Harbour Engineer, had not been fixed radially in the proper manner. The roller-path had been set out correctly to a radius of 32 feet, but the centre-line of the spindle to the carriage of the west gate had been found to line 18 inches off the centre of the pintle, or heel-post. It was not only necessary to have a roller-path set out properly, but great attention should be paid to the way in which the carriages were fixed, otherwise there would be a compound sliding and jumping action. The result had been that the upper portions of the attachments had to be removed from the roller-carriages of the Granville dock-gates, and two new carriages, fitted with phosphor-bronze bearings, bored to suit the roller-pins, the tail end of each carriage being bored to take the present pins, so as to reduce the wear upon the roller-path caused by the jerks experienced. The gateway had been occasionally closed for repair since the gates had been fixed, due to their position exposing them to heavy wear and tear. The centre-line of the spindle to the roller-carriages should of course radiate from the centre of the heel-posts. When the gates had been made they had been ballasted with tar. He should not advise that to be repeated, as, in the first instance, it was not adjustable at different heights of the tide, and in the second, when the gates were closed for repair it was difficult to repair a leak. If there was a loose rivet the tar would escape, and a plug had to be inserted, making an awkward job. The consequence had been, that during 1894 the tar had been replaced by water, which gave greater satisfaction, because it could be adjusted to different heights of the tide. The gates had a 65-foot opening, and there were 21 feet of water over the sill at ordinary high-water spring tides.

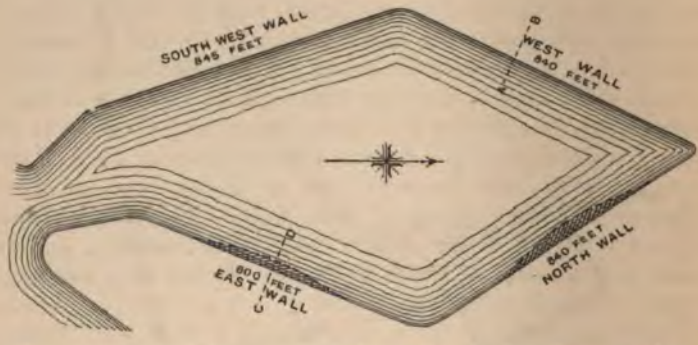
Mr. Galbraith. Mr. W. R. GALBRAITH remarked that the dock-walls at Kidderpur might be described as light walls floated upon a doubtful foundation. They seemed to be as light as possible by being constructed hollow and floated upon a mass of brickwork more than

30 feet wide and 11 feet thick. The result of that, as far as the downward pressure was concerned, seemed to have been successful, but as regarded the resistance to thrust at the back he thought the flat floor of the foundation had been a mistake. If the wall had been canted so as to throw the heel backwards the probability was that it never would have moved. The pressure at the back had caused the wall to move forward, being on a slippery foundation, because there had been no resistance. The berm or mound in front had not been sufficient to resist the thrust. He asked if concrete had not been considered, or whether it had been available. The foundation seemed to have been doubtful; the bottom had risen once or twice, and if concrete had been available, it was much better and could have been much more quickly put in than the mass of brickwork. Possibly there had been reasons for concrete not having been used. It had been mentioned by Sir Douglas Fox that in some places a pressure of not more than 2 tons per square foot upon clay had been decided upon. It was a doubtful material; but he considered that any of the London clays ought to stand more than 2 tons per square foot. At the docks at Southampton, where there had been a good many mishaps, it was found that the clay could resist a much greater weight than 2 tons per square foot. The Empress dock at Southampton presented an instance of the slipping of three walls. The dock had been designed by the late Mr. Alfred Giles, Past-President, and extended over an area of about 18½ acres. It was of a somewhat peculiar shape, *Fig. 1*, but in working it was found to be most convenient, for vessels could enter and leave it with great facility. The large American steamers, the "Paris" and the "New York," went in and out of the dock with the utmost ease. The rail approach from the north-west angle passed readily round the docks, and the London and South-Western Railway Company's trains ran at all times round the sides. The designer had so far been right in regard to the shape of the dock and the position in which it had been placed. The works had been carried out entirely under Mr. Giles's superintendence, but the London and South-Western Company had stipulated that their resident engineer, the late Mr. W. Jacomb, should see to the measurements of the monthly certificates. On the death of that gentleman it had fallen to his lot to attend to the matter, so that, although he was in no way responsible for the dock works, he had seen a great deal of their construction. The dock was 26 feet deep at low-water of spring tides, and the total height of the wall was 51 feet. The

Mr. Galbraith.

Mr. Galbraith. wall was almost level at the bottom, the inclination being 1 in 60, with a 6-inch slope backward from the face. The thickness at dock-level was 25 feet, and at the base 30 feet. The walls round the dock had been constructed on the foreshore which was covered at high water. The plan had been adopted of raising a reclamation bank round the whole work, and the docks were excavated in the dry. The bank had been an entire success, and there had been no leakage after it had been constructed. With regard to the strata in which the wall was built, there was first about 17 feet or 18 feet of mud, then a bed of peat, then a bed of gravel, and then blue laminated clay. The dock had been excavated to about 15 feet from the bottom, and the lower part of the wall had been built in a trench. The concrete was 8 to 1, better concrete of 5 to 1 being used for a smooth face to the wall. The

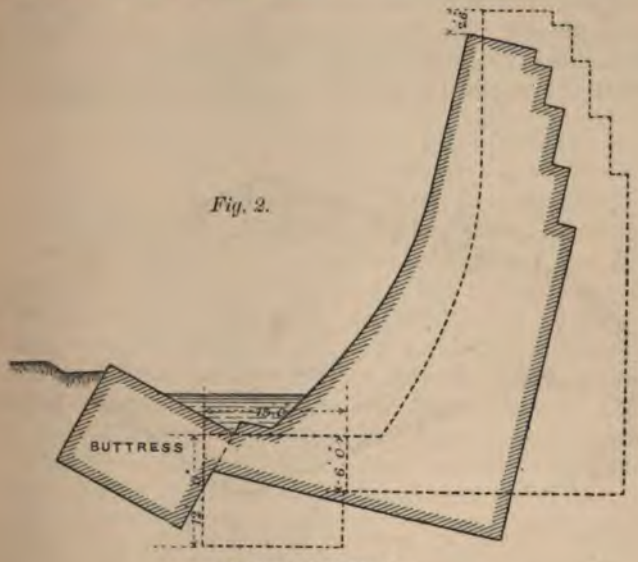
Fig. 1.



walls were backed by material from the dock. The north wall was built up to the coping-level and fully backed up. In September 1888 there had been a slight movement of the wall throughout the day, and the same evening the whole had moved bodily forward about 13 feet in a few minutes. The wall had not broken up, but moved forward, at the same time keeping its vertical position. During the course of the next day also it had moved about 10 feet, the total movement being 23 feet. The length affected was about 400 feet. The ground in front of the wall had been excavated to the full depth, and there was a resistance of about 6 feet of earth at the toe. When the wall had moved it had pushed the clay bodily in front of it, raising a large mound. The wall had been ultimately taken down for 400 feet but instead of being rebuilt 6 feet below the dock bottom, the foundation had been carried 15 feet, and this had been found

to be effective. The wall had been in perfect order, undoubtedly, until it had been backed up, and the excavation taken from the toe with the exception of the 6 feet. Then the wall had moved forward, entirely, he considered, on account of the heavy backing. He believed that not only the backing, but the clay and the mud from behind for some distance had moved bodily forward. Water, he thought, had penetrated below the wall to cause it to slide. He might mention that when the north wall had failed, the foundations of other walls had been inserted, and a question had arisen as to what steps should be taken Mr. Galbraith.

Fig. 2.



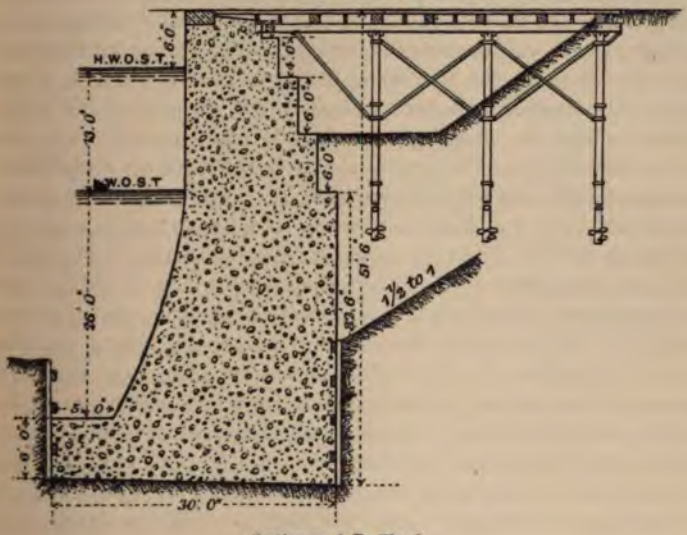
Section on C D, *Fig. 1.*
Scale, 20 feet to 1 inch.

to secure the other walls. It had been determined to build buttresses or counter-forts at the toe, *Fig. 2*, so as to give a greater resistance, 20 feet long, 15 feet wide, and 12 feet below the dock-bottom. There was a space of about 30 feet between the buttresses, which had been built also in the cases of the east, the west and the south walls. The construction and backing up had proceeded until May 1889, when the east wall had moved, but in a different manner from the north wall. The section on C D, *Fig. 2*, showed the movement of the east wall, and it would be seen that the wall, in moving forward, had forced the buttress upwards, and dropped back. The forward movement of the coping had not

Mr. Galbraith. been great, but at the bottom of the wall it had been about 13 feet. In addition to the slippery foundation, a quantity of water had come through from the quay-wall of the river Itchen. There had been cracks in the wall, and the water had softened the ground behind the wall. When it had moved forward, it seemed at the same time, owing to the soft nature of the ground behind it, to have dropped. The length of the portion in which the movement had occurred was about 400 feet, and it had ultimately to be taken down and rebuilt. The foundations had been carried to about 15 feet below the dock-bottom. He thought the occurrence was due to the same cause, viz., the slippery bottom, the flat floor of the wall, and the want of resistance. The resistance offered by the buttress had not been enough; but he thought it would have been so except for the unfavourable circumstance of the extra water and the inflow from the river Itchen. After that had occurred, a large amount of material had been placed on the toe of the wall to load it down while the water was being let into the dock, which had been opened without further mishap; but some time afterwards a movement had occurred in the west wall. After the dock had been opened and the warehouses erected and loaded, the west wall had begun to move; and as a precautionary measure, Mr. Giles had excavated the ground behind. The quay and part of the shed were carried on a framing or gantry consisting of screw piles with timber top, *Fig. 3.* In that way the wall had stood for a time, but in 1893, after the South-Western Railway Company had taken possession, the wall had begun to move again; the sheds had settled, and the piles cracked and broken. The wall had continued to move slowly, and it had been feared that it would fall bodily. The dock had been full of water, and the plan of sinking between each pair of buttresses two large 14-feet cylinders, 20 feet below the dock-bottom had been adopted. Upon these cylinders and the buttresses a new face-wall had been founded and carried up in front of the other. That work had been almost completed and the space occupied by the gantry was being filled in. With regard to the strength of the wall there was no doubt that it was sufficient, but the slippery foundation and the small resistance to the thrust had been overlooked. There was not enough ground in front of the toe, and the result had been the unfortunate disasters which had occurred. Adjacent to the east wall was a wall nearly as large as the others, but not nearly so heavy, being only 21 feet thick at the bottom; in the bottom piles, however, had been driven and the concrete deposited in and around them. That seemed to have held the bottom, though it was of much smaller size, and showed that if

some such precaution had been taken in the case of the Empress dock the disasters in question would not have occurred. The south wall had not moved, and he thought the reason was, that whereas in the case of the north, the east, and west walls the ground was filled in behind the wall for a long distance, so that there was no vent for the material except against the wall, in the case of the south wall, which had stood, the backing was narrower and had a vent seawards, so that the whole thrust of the backing did not come against the wall. The Empress dock at Southampton, he thought, showed the importance, in clay foundations, of carrying the walls Mr. Galbraith.

Fig. 3.



Section on A B, *Fig. 1.*
Scale, 20 feet to 1 inch.

to a considerable depth, or of taking other precaution to prevent slipping.

Mr. H. WARD had placed a number of photographs on the table showing the slips in the excavation and the timbering used in the trenches in the construction of Tilbury Docks.[1] The timber used there had been of heavy description. The frames had been about 3 feet apart vertically, centre to centre, but in some cases they had been placed at 4 feet. The walings and struts were 12 inches square, about 6 feet apart longitudinally, with 2½-inch runners at Mr. Ward.

[1] Minutes of Proceedings Inst. C.E., vol. cxx. p. 276.

Mr. Ward. the back. It had been hardly possible to get more than about four of those frames—about 12 feet of depth—in one setting. It was then necessary to take a setting inwards to get a fresh frame. It had to be carefully decided, before starting a trench at the top, how many settings of timber were likely to be needed to obtain the extra width necessary for the internal frames. The amount of timber had averaged as nearly as possible 3 cubic feet per lineal foot of trench on each side. That, he thought, was almost unprecedented in the way of heavy timbering. A slope of $1\frac{1}{2}$ to 1 had first been tried, then 2 to 1, then 3 to 1, and finally it had been necessary to leave 6 to 1 slopes where no walls existed. From the timber used at Kidderpur, it did not appear that the ground was quite so bad as that met with at Tilbury, for he noticed that it had been possible to get 20 feet deep without any internal setting. He had examined the photographs, and apparently only $2\frac{1}{2}$-inch runners had been used. It was hardly possible to drive a $2\frac{1}{2}$-inch runner 20 feet deep if there was great pressure at the back of it. The friction at the back, forcing the runner forward on the wedges at the back of the waling, was so great that it was rarely possible in heavy ground to excavate more than 12 feet or 15 feet in depth without internal setting. He noticed in the photographs of the Kidderpur docks that no steam-cranes had been used, the whole excavation having been cast up hand-over-hand. He presumed that labour was cheap, while plant and materials were dear. The walings appeared to be half timbers, as the cross-struts were only 4 feet 6 inches apart. Had cranes been used it would have been necessary to have placed the cross-struts farther apart, to allow the buckets to pass easily between them. He thought it would have been found somewhat more economical to use fewer struts and stronger walings. Many examples of finished works had been described in the Proceedings, but there were few illustrations of failures. When an engineer came forward, as Mr. Bruce had, and frankly put everything, failures as well as successes, before the Institution he was entitled to the warmest thanks of the members. Engineers sometimes boasted that they had had no failures, he thought then they had hardly done their duty to their clients. It was quite easy, or at any rate fairly easy, to avoid failures if enough material was used, but if the engineer was desirous of executing the work as economically as possible, it was almost essential that he should sometimes fail: he could not provide against every possibility in designing dock-walls. No doubt in many parts comparatively thin walls would be amply strong; but in certain cases which could hardly be

known beforehand the ground was so exceptional that a much heavier wall was required. It was not possible to decide upon the conditions until the work had been opened up and certain failures encountered. It seemed to him that Mr. Bruce had provided for everything that could well have been foreseen. The wall was 34 feet or 35 feet high above the dock-bottom, while the thickness at the bottom was 35 feet. That seemed a large provision, and it was difficult to understand how the wall had been pushed forward. He thought there might be something which was not fully appreciated. An examination of the Tilbury photographs would show that many slips had occurred, not in the trench work, but laterally, the grass surface of the marsh being raised by the pressure of the tip-head. About 14 feet of excavation had been tipped over the whole surface of the marsh, and occasionally the grass surface of the marsh, some 50 feet in front of the tip-head, had risen to a height of 6 feet or 8 feet, while the tip itself had sunk, and the intervening space sometimes of 20 feet or 30 feet outwards from the bottom of the tip had not been altered in level. The part of marsh raised was 40 feet, 50 feet, or more distant from the tip-head, in front or at the side. Generally there was a ditch in the neighbourhood, which probably tended to cause such movement. The ground itself consisted largely of peat in layers and what had been called "clay" or "mud"; but he thought it was safer to call it alluvial deposit. The ditches had allowed the water to get to and through the peat, and thus soften the mud or clay below. Often there had been a hard top surface, which apparently had been able to resist upward pressure, and the weight of the tip-head on that top had conveyed pressure down to a kind of pipe, as it might almost be called, and thus thrust up the marsh some distance from the tip-head where it had not the weight of the tipped material to support it. So it was possible in the Kidderpur dock-walls, that the top of the backing, being exposed to the hot sun, might have become indurated. When water had been let into the dock, the lower clay backing where exposed to water would swell one-fifth of its bulk. If the hard surface remained intact, there might be a horizontal pressure under it, tending to force the wall forward. He could not understand otherwise how a wall 35 feet thick and only 35 feet high could have moved. He was unable to appreciate why brickwork had been used, but gathered that there had been a difficulty in obtaining concrete material. Where bricks could be made he thought concrete material ought to be obtained. Of recent years a good deal of concrete had been made of burnt ballast; and he

Mr. Ward.

Mr. Ward. thought that if bricks could be obtained, clay could be burnt to make concreting material from the burnt ballast. Sufficient sand could no doubt be obtained from the river to mix with the burnt ballast so as to make the whole solid. He did not quite appreciate the desirability of keeping the dock shallow and incurring the permanent expense of raising the level of the water by pumping. It had been adopted in several instances recently in old works, but he was not sure whether it had been deliberately proposed in designing new works. It was used at the Albert Docks, where the plan was to pump water into the dock to the level of high-water of spring tides at all times. Great saving might be effected in dock-walls by raising the water-level inside. Still it seemed to him that the expense of pumping, and the staff it would be necessary to keep up during the whole time, must largely counterbalance the saving in capital outlay. It would be helpful to engineers to know the conclusions of those gentlemen who had special experience in that direction.

Mr. Hawkshaw. Mr. J. C. HAWKSHAW thought that both the Papers were of unusual interest to dock engineers. The cost of keeping the docks free from sediment in muddy estuaries was often considerable, and some such arrangement as that provided by Mr. Bruce might probably be adopted more frequently with advantage. It was some time since he had had a return of the amount dredged from the Hull docks; but on the last occasion on which he had received such a return, the amount dredged per year for some years had been about 1,250,000 tons, and he thought that the total cost of dredging the docks was about £12,000 a year. He remembered taking out at the same time the cost of dredging the docks at Liverpool, which was more than double that amount, viz., £25,000 a year. Not only might the cost of dredging be saved by pumping water free from sediment into docks, but the inconvenience and disturbance to trade caused by the dredgers working in the docks might be avoided. In the case of the Kidderpur docks it was also possible to maintain a constant head of water, which was certainly an advantage. The amount of sediment in the Hooghly seemed large. Three cubic inches in a cubic foot in a time of flood was more than 1 in 600. In the water of the River Plate the amount of sediment had been ascertained to be 1 in 10,000 by weight.[1] With regard to the dock-wall, the construction of it in two halves was of course a somewhat unusual proceeding; but the width at the base was also unusual, being nearly the same as the height

[1] "The Hydraulics of Great Rivers," J. J. Révy, 1874, p. 23.

of the wall above the dock-bottom. Mr. Apjohn's description of the failure was most complete and instructive. A wall of the section shown might be expected to be stable on most sites. It only showed the necessity, in designing dock-walls for estuarine formations, of knowing if possible something of the behaviour of the material, and the slope at which it would stand. The nature of the material forming the toe of the dock-bottom in front of the wall was almost of greater importance than the nature of the material forming the backing. He thought there were no more difficult sites to be dealt with than those in estuarine formations, where beds of sand and peat were mixed together. There were many examples in this country, the case of the Southampton docks being one; and no doubt many of the failures of dock-walls which had occurred had been in such formations. The Authors were to be congratulated on having rightly judged that the proper way to deal with the failure that had occurred was to let water into the dock, and on not having had recourse to more expensive methods for preventing further forward movement. Mr. Hawkshaw.

Mr. A. C. Hurtzig wished to congratulate Mr. Bruce on the adequate and complete equipment which had been provided for the docks. It was not unusual for new docks to be built to take the finest ships, and yet, when they were opened, for it to be found that no ships could use them, because their cargoes could not be properly dealt with. The resources available had been husbanded in such a way as to provide a dock, which at the commencement of its career, was incapable of dealing with very large cargoes. With reference to the general design he should like explanation as to the necessity for the half-tide basin; it seemed to involve the additional expense of separate entrances from the half-tide basin into the dock, which, in his opinion, were entirely unnecessary. He could not see why the half-tide basin should not have been a portion of the dock. The ingress of a vessel into that dock through the lock only would be accompanied by a loss of a small amount of water. The level in the half-tide basin, it was said, might fall as low as 9 feet above datum. That could not be used as a means of communication with the main dock until it was levelled up to about 20 feet above datum. He considered that no difficulty would have been experienced in the manipulation of vessels of any size or character if the half-tide basin had been merged into the dock, and become part of it, and more accommodation would have been provided inside. With regard to the entrances, one, the 60-foot lock entrance, pointed up-stream and was for the accommodation of the vessels coming Mr. Hurtzig

Mr. Hurtzig. up on the flood-tide. The other entrance pointed down-stream, for use in the case of flood when there was always a downward current. Why that entrance had not been made as a lock instead of a simple entrance he did not understand. If the basin were part of the dock proper, the facilities of ingress and egress would be superior to those at present available, because the water-level would always be of the necessary height; whereas now, if the water in the basin was at low level, it had to be levelled up from the dock, involving a considerable amount of pumping. The system of keeping up the dock-level by pumping in clear water was an important and valuable one. The cost of dredging the old Hull docks had been stated by Mr. Hawkshaw to be about £12,000 a year. It was, he thought, somewhat more than that. The Alexandra dock at Hull,[1] designed by Mr. Abernethy, extended over an area of 46½ acres, while the area of the old docks was about 110 acres. Nothing had been spent upon the dredging of the Alexandra dock since its opening in 1885, on account of its level being maintained almost entirely by pumping from another source rather than admit water from the Humber. He thought that the method adopted by Mr. Bruce had been of the greatest possible value to the proprietors of the Dock Estate. With regard to the dock-walls, the design was an unusual one, and the great width of 35 feet in the base was in his opinion unsatisfactory. Such expensive excavations and timbering in trenches must have added greatly to the cost of what he might call a normal dock-wall. At the Alexandra dock at Hull there was a depth of 40 feet from the coping to dock-bottom; at Kidderpur it was only 35 feet. The width of the bottom of the dock-wall to which he had referred was 20 feet. Its foundation was 11 feet below the bottom-dock instead of 10 feet, and it was 6 feet wide at the top. The cubic capacity of the wall was 83 yards of masonry to the yard forward; that of the Kidderpur wall, excluding pockets, was about 99 cubic yards to the yard forward. Those pockets could not be considered an integral part of the wall. If the front or back skin of the wall was not water-tight the earth filling became saturated with water, and had a thrusting-out effect upon the front section of the wall, which he thought ought to be contemplated. Again, the back skin of the wall was not like a part of a dock-wall of solid masonry, and it could not be assisted by the interior filling of broken bricks or earth. He did

[1] Minutes of Proceedings Inst. C.E., vol. xcii., p. 244.

not think that a pressure of 4·2 tons per square foot upon strong clay was in any way excessive, or that it could be regarded as the cause of the failure. The longitudinal crack which had been mentioned as existing in the walls was, he thought, a suggestive feature, showing that the monolithic character which ought to appertain to a dock-wall did not exist in the case in question. At Southampton dock the whole wall had moved forward, due largely to the small toe and the inefficiency of the foundation, but in the case of the dock-wall at Kidderpur there was a longitudinal crack. He did not understand how it could be accounted for except by the yielding of the interior material in the pockets, which allowed the front to go forward and move away from the back. He thought that feature of the design was unsatisfactory. The arrangements of the sheds, &c., in the dock seemed to be good, and he should think there could be no possible complaint from persons using the dock. The way in which the difficulties and failures had been met had, in his opinion, been skilful and suitable to the requirements of the case. Mr. Hurtzig.

Professor W. C. Unwin had received a letter from Mr. Apjohn asking him to be present at the discussion and to reply to any question that might be asked; but he did not feel that he had sufficient information for the purpose. He might, however, remind Mr. Hurtzig that Mr. Apjohn had attributed the longitudinal crack of the wall to the fact that the foundations were built in halves, and that there were two different settlements of those separately built portions. Prof. Unwin.

Sir Benjamin Baker, Vice-President, wished to know if the Authors could give any further information as to the nature of the material below the base of the wall. There was a general statement that the soil was sandy clay and of putty consistency. Most engineers knew what that meant, and it would be hardly surprising for anything to happen when a material of that kind came into intimate connection with water. It could easily be imagined that even if there were no lateral pressure of earth against the wall, but merely an unequal vertical pressure such as there must be where there was a mass of earth of considerable height on one side, and the dock-bottom on the other, there might be a movement in the whole of the ground from the vertical settlement, causing a lateral movement of the ground and whatever was upon it, whether a dock-wall or a turnpike road, or, as in the case of the Great Western Railway at Hanwell, a small river, known as the Brent, which had been translated laterally several yards, simply by the pressure of the railway embankment some 50 yards Sir Benjamin Baker.

Sir Benjamin Baker.

distant from the spot. It would, therefore, be interesting to know whether there had been any evidence of the ground itself upon which the wall rested having moved laterally. If the wall had not slid, but the ground upon which it was built moved laterally, it was clearly a matter of indifference whether the base of the wall was horizontal or whether it sloped back at 1 in 24 or at a still greater slope. Most engineers had had experience of such movement of walls. He did not know whether Prof. Unwin would agree as to the direction of the lateral thrust of the earth as shown in *Figs. 9* and *10* of Mr. Apjohn's Paper, which he thought exaggerated the actual tendency to slide. At Tilbury he had seen movements of timber trenches in which there was really nothing to disturb them except unequal vertical pressure, there being no unequal lateral pressure or thrust at all and no question of sliding on the base. There had been afforded a good example of lateral movement without direct lateral pressure in the slips at Sandgate[1] in March, 1893. He had examined the matter closely for the South Eastern Railway Co., and his recollection was that a row of coastguard cottages, about 300 yards long, had moved forward laterally in the same way as the dock-wall; but certainly they had no earth pressing against them to bring them forward; it was simply that the sandy clay of the cliff, which had become saturated by the exceptionally heavy rainfall, had undergone a vertical settlement, and that had caused a lateral movement carrying the row of houses in a wavy line, although they were as far from the slope of the cliff as the other side of Great George Street was from the Institution meeting-room.

Mr. Bruce.

Mr. BRUCE, in reply, pointed out that the section of the dock-wall shown in the diagram exhibited was incorrect. He had referred to his original drawings which showed that the foundations had been put in at right angles to the face of the wall. Up to the time he had left Calcutta the walls had been constructed in that way, and he had never heard from Mr. Apjohn that that arrangement had been changed. In the drawings, as shown in Figs. 25–27, Plate 2, the foundations, instead of being level, were shown at right angles to the batter, 1 in 24, giving a fall of about 18 inches to the back. He had never seen such movement as Sir Benjamin Baker had described. In fact, when the excavation with side slopes of 3 to 1 had been made, the timbered trench at the bottom of the excavation had as much weight on one side as on the other, and there had been therefore no possibility of the trench moving

[1] *The Times*, March 6, 1893, p. 6.

forward. When the trenches had been cut there had been several settlements, and the bottom of the trench spewed up, but there had been no other movement. The measures taken to avoid the settlement and spewing up of the trench had been, as pointed out in the first Paper, the sinking of a series of pits along the line of the foundations instead of cutting a continuous trench. With regard to the necessity of a half-tide basin, that had been decided on in consequence of the docks being kept at a much higher level than the river, and the fact that it was intended to extend the docks considerably beyond their present length. If the docks had been kept down to the same level and worked at the level of high water in the cold season in Calcutta the docks would have had to be made about 5 feet deeper than at present; and the vessels going in and out, except those which could enter on the top of high water, would have had to be taken in through the lock. It had been thought that if all the vessels had to be taken into the docks at once, it would not be possible to pass the number in and out in the time available, which never exceeded an hour and a half in the Hooghly. After the tide had set down about an hour the stream was so strong that no vessel was allowed to be moved. Ships could only be taken in and out at high water. With regard to Mr. Colson's statement that the basin walls would be in a dangerous condition if the water had to be much lowered, he might mention that no movement had ever taken place in the walls of the basin, the movements being entirely restricted to the dock-walls, and as these had taken place under conditions which could not again obtain, he did not consider there was any risk of an accident happening to the walls in question. It should also be mentioned that the material found at the entrance basin was very much better than that met with in the dock. The ground was much more solid, and no slip had occurred in the construction of the half-tide basin. Under no condition except that of pumping out the water could there be less than 20 feet of water against the basin walls, and even that depth would only be reached if by any accident the water in the basin fell to the level of low water in the river at spring tides. The conditions under which it was intended to work the basin contemplated the level being lowered to 26 feet over the sill, and if an accident happened to the gates which would prevent the water being retained at that level, the caissons would be available to place in position and close the entrances. It had been suggested that as caissons were to be used they might have been made to take the place of the gates, but if sliding caissons had been adopted

Mr. Bruce.

Mr. Bruce. they would not have been available to move about in the manner for which the present caissons had been arranged. The adoption of caissons, however, instead of gates, had never been contemplated, as the great difficulty of keeping the chambers clear of silt in the Hooghly was, in his opinion, a sufficient reason for not adopting such an arrangement. It had been the experience of the disastrous cyclone of 1864 that had led him to consider the advisability of adopting caissons. On that occasion the centre of the cyclone had passed up the south of the Hooghly and produced a cyclonic wave which, as it advanced up the river, rose to a height which had been variously stated by different eye-witnesses at between 16 feet and 20 feet, and swept all of the vessels in Calcutta from their moorings. A similar occurrence might cause great damage to the outer gates, and it had been to guard as far as possible against any chance of such an accident that it had been decided to have the caissons in readiness and to place them in position outside the gates whenever a cyclone was approaching Calcutta. It should be borne in mind that no year passed without one and sometimes two cyclones occurring somewhere at the head of the Bay of Bengal, and although they did not produce any serious effect at Calcutta, except when, as in 1864, the centre of the cyclone passed up the river, still it had been arranged that whenever a cyclone was blowing at the sand-heads, the caissons were to be placed in position to protect the gates. With regard to Mr. Vernon-Harcourt's remarks as to the rollers on the dock-gates, the question had frequently been discussed before the Institution. When he had taken charge of the works, Mr. Apjohn had been anxious to dispense with the rollers, but after carefully considering the matter and obtaining the opinion of several engineers who had long experience in the working of large gates, Mr. Bruce had decided to adhere to their use. The cost of the rollers and paths added little to that of the gates and entrances, and seemed to him to afford additional security should the gates through any accident become filled with water. Without the rollers there must be considerable friction on the heel-post and on the lower pivot, necessitating much more power to work the gates and producing considerable wear and tear on the lower half of the heel-post. For small gates he did not consider they were required, but for 50-foot and larger he thought they should be adopted.

He agreed that if the walls had been built on a hard foundation it would have been an improvement to have had the face vertical and even corbelled out at top to meet the tumble

in at dock-level which most steamers now had, but as a certain amount of settlement on the foundations was to be expected at the toe of the wall, he considered it advisable to build those walls with a batter. One reason for the walls not having been built of concrete instead of brickwork was that there was no material other than broken bricks obtainable in Calcutta suitable for making concrete, and another that the cost would have been considerably increased. Suitable concrete could only have been made with cement, which would have had to be imported, while the brickwork had been constructed with ghooting lime obtainable on the spot. Cement concrete would have cost about Rs.55 per 100 cubic feet, while brickwork in ghooting lime cost Rs.30. A double entrance between the basin and the dock had been thought by Mr. Vernon-Harcourt unnecessary. That was a point which received serious consideration before the commencement of the works. In submitting the project originally to the Government, it had been pointed out that one entrance would be sufficient and that a considerable saving would be effected by omitting the second. A Committee appointed to report on the subject, however, had decided in favour of double entrances, and they had been accordingly constructed. The dock could of course have been worked with one entrance, but it would be a serious matter in such a case if anything occurred to obstruct the entrance. He might mention that just at the time when the matter was being considered, an accident had occurred to one of the gates of the Bombay docks where there was a double entrance similar to that shown in the Figs., and which resulted in the stoppage of one of the passages for a considerable time. That accident had had great weight in inducing the Committee to recommend a double entrance. The lower entrance with the single pair of gates was intended to be used during the rainy season, when the current was always down stream, and to admit vessels which arrived at the top of high water direct into the basin. On spring tides in the Hooghly it frequently happened that there was a considerable downward current in shore while the tide in the centre of the river was still running up. At such time the lower single entrance would be more convenient than the upper lock.

Mr. Bruce.

In his original calculations he had found that the mean pressure on the foundations of the walls would be about 2·1 tons. Assuming the natural slope of the ground to be 3 to 1, he found, with the backing filled in and no water in the dock, there would be a pressure of 3·8 tons per square foot at the toe of the wall, and

Mr. Bruce. 0·4 ton at the back. It was because he thought that pressure on the toe of the wall too great that he had recommended the berm to be left, and no backing to be put in above berm level till water was admitted to the dock. With 28 feet of water in the dock, the pressures were 2·44 tons in front and 1·78 ton at the back. That question had been fully dealt with in the report[1] on the project, which would be found in the library of the Institution. With regard to Mr. Lewis's remark that he had been many years ago connected with a scheme for docks in Calcutta, and that the objection then raised was that it would be impossible to keep the water from becoming putrid on account of the climate, he might say that similar objections had been raised to the present scheme. It had been admitted that the proposal to pump the water into the dock would to a great extent overcome the difficulty; but it had been asserted that a large body of water in the position which the docks occupied would tend to raise the level of the subsoil water and make that suburb of Calcutta more feverish than it was at present. So serious had the question been considered that the Government had appointed a special Committee to inquire into it, and a copy of that Committee's report[2] and of the evidence given before it would be found in the library of the Institution. Regarding the opinion expressed by Mr. Shelford, that the slip on the east wall was due to an inclined plane of clay below the east wall and sloping from it to the west wall, and which would necessarily offer an opposing force to the movement of the west wall, he did not think that was borne out by an examination of the facts. The south end of the west wall had moved, and in a direction opposite to the incline which was thus considered to oppose its movement. He had previously mentioned the conditions under which the backing had been inserted, and the absence of drainage arrangements, and in that would, he thought, be found the true cause of the movement of the walls. In that opinion he was further confirmed by the fact that the filling in behind the south-west wall, where the most serious movement had taken place, was much deeper and more extensive than in any other part of the work. When the docks had been originally designed, it had been intended to carry the west wall in a straight line to the end of the dock; but it had subsequently been decided to incline the last berth as shown, and so save the construction of a considerable length of

[1] Selections from the Records of the Government of India, Public Works Department; Serials Nos. 4 and 9.

[2] *Ante*, p. 123, footnote.

wall, which would otherwise have been of little service as quay space. The excavation for the straight wall had, however, been taken out for the whole length to a depth of about 10 feet below datum, and there was consequently a much greater depth of made ground behind that length of wall than at any other place. That made ground would become much more easily saturated with water than the banks which had not previously been disturbed, and it was, he thought, due to that fact and there being no adequate drainage that the movement in that wall was so much more serious than at the east wall. In his Paper Mr. Apjohn had given the forces which, in his opinion, were acting upon the dock-walls, and the support which was given to them by maintaining the level of the water at 16 feet and 20 feet above datum, and he had recommended that the latter should be adopted as the lowest point to which the water should be allowed to fall. He also showed, however, that when the water had been admitted into the docks immediately after the accident, it had only been allowed to rise to about 14 feet above datum, at which level it was kept until the completion of the works. As the walls had stood for over a year with the water at 14 feet above datum without the slightest sign of movement, it seemed evident that they were quite safe with this depth of water on the sill, and that, with the exception of the saving in dredging which would result from adopting the higher water-level, no advantage whatever would be gained. On the other hand, the entrances had been designed to be worked with a depth of only 16 feet above datum during the dry season, or 2 feet higher than the depth at which the water had stood during the completion of the works. At neap tides in the dry season the river was only between 10 feet and 12 feet above datum, and by maintaining the minimum level of the dock at 20 feet during this season of the year, a much greater amount of pumping would be required than if the level were maintained at 16 feet as originally proposed. It would also involve a much greater use of the lock between the river and the basin than was intended, and would seriously interfere with the entrance and exit of vessels as the numbers using the docks increased. There was no necessity to maintain the level of the water at more than 16 feet above datum, and that depth would ultimately have to be adopted and the docks dredged out 4 feet deeper than they were at present. With regard to the manner in which the work had been carried out, he would like to add that he had never seen a finer piece of brickwork, and that he considered the greatest credit was due to Mr. Apjohn and his assistants, Mr. Soutter and Mr. Gaskell, for the manner in which the

Mr. Bruce.

Mr. Bruce. work had been executed in India. A mistake had been made in filling in the backing, but the damaged portion of the walls had now been repaired, and by the construction of short boat-landings at the south-west and north-east corners, where most damage had been done, all traces of the accident had been removed, and no one now visiting the docks would know that any movement had ever taken place.

Mr. Apjohn. Mr. J. H. APJOHN, in reply, agreed with the opinions expressed that the bottom of the wall should tilt back; and if any extensions had to be made, he would construct the wall vertical on both face and back, rising, say, 5 feet in its 35 feet of thickness, the whole thickness being built in one piece. He would adhere to the pockets filled with earth to save brickwork, but the tunnel had been a mistake. It was not so convenient for the pressure pipes as a chase in the coping, and the atmospheric conditions within it were unsuited for electric-light wires. With regard to the gate-rollers, he had objected to them from the first, and though unable to maintain his objection, had had them so constructed that they could be thrown out of gear from above. Soon after water had been admitted the rollers had given trouble; they had been thrown out of gear, and the gates had worked perfectly without them. If the lock had been long enough to take in the largest ships, instead of only 400 feet, it would do all the work; but the other entrance was convenient at times, when the level in the river rose to the basin-level, or the latter had been lowered to that of high-water in the river. The caissons were not for excluding a swell, but either a cyclone wave rising higher than the water-level in the docks, or very high tides, when the river was in flood, which occasionally rose almost to coping-level. If he were again to build the docks, he would provide reverse gates in the river-entrances. The method of feeding the docks worked well. The water deposited all its silt in the canal, which was dredged out to the extent of about 1,000,000 cubic feet a year. About 3,000,000 cubic feet of water were daily pumped into the docks, so the deposit was about $\frac{1}{10}$ per cent., or almost exactly that which is found by experiment on samples of the water to be the mean proportion of silt contained in it. The maximum lift for the pumps was about $11\frac{1}{2}$ feet against 10 feet specified; and the full duty of 250,000 cubic feet an hour for each of the three 36-inch pumps was obtained.

Correspondence.

Mr. F. T. Bagshawe, in the absence of a plan showing the formation of the surrounding country, was unable to judge of the contour of the land about the site of the docks, but suggested that the sliding forward of one side only of the dock-wall might be due to the general slope of the ground in one direction. The wall on the side towards the higher portion of the slope would have to resist not only the pressure due to the backing, but in addition the whole weight of the side of the hill into which it was cut. With the wall on the side towards the lower portion of the slope it was quite the contrary, for the action of gravity had a tendency to relieve it not only of all pressure of earth from the side of the hill in which it was situated, but also even of the pressure due to the backing. Such an instance had been met with last year in the widening of a railway cutting through sandy clay and construction of the concrete walls. It had been found that on the high side of the hill 6-inch square struts and 12-inch by 6-inch walings, in 12-foot lengths, were necessary; but on the opposite side of the cutting the same work had been executed, though the wall was about 5 feet higher, by the aid of only 9-inch by 3-inch planks used both as struts and walings. Mr. Bagshawe.

Mr. W. Dyce Cay considered that it would have been better in such strata not to have carried the excavations and masonry of the foundations to the depth of 10 feet below the proposed dock-bottom, but instead to have supported the dock-walls on bearing- and sheeting-piles.[1] This would have been cheaper and equally good in every respect, and would have had the effect of solidifying the surrounding strata. It had been stated by the Authors that the slipping of the walls would not have occurred if the water had been let into the dock before the backing had been brought up behind the walls. In some cases of difficult foundation it was better not to keep the water out at any time, but to execute the work under water, which, with modern appliances and methods, was not necessarily difficult or costly. Mr. Cay.

Mr. A. F. Fowler remarked that it was important in most cases for a dock-entrance to be situated parallel to the direction of the current, which should be down-stream to avoid the necessity Mr. Fowler.

[1] Minutes of Proceedings Inst. C.E., vol. xcii. p. 177.

Mr. Fowler. of swinging inbound vessels. The general plan, Fig. 1, Plate 1, gave no indication of the river contours, and the down-stream direction might not be desirable at Kidderpur, owing to the velocity of the current and the consequent difficulty of controlling vessels entering on the flood-tide. But when the current was down-stream throughout both phases of the tide, it would appear that this difficulty would be experienced at the upper or lock-entrance, and would be increased by vessels having to swing; also that at such times the lower entrance would have to be approached across the current.

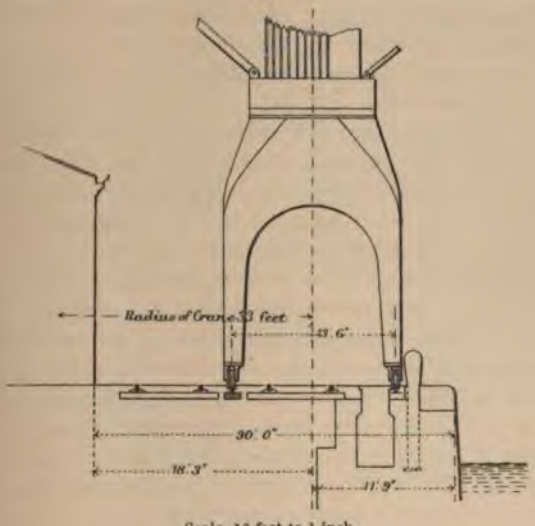
With regard to convenience in dealing with the shipping and in saving water, the advantages of the usual practice of constructing the lock between the tidal basin and the dock were so obvious, more especially in reducing the range of variation of the water-level, that it was difficult to understand why it had been departed from at Kidderpur. If two single gate-entrances had been provided between the river and the tidal basin and a lock between the tidal basin and the dock, one pair of gates would have been saved without increasing the risk of stoppage referred to in the first Paper. His experience would induce him to dispense with gate-rollers, and to give a slight rise in the horizontal members of the gate between the heel-post and the mitre-post, to counteract the sagging tendency. The masonry behind the hollow quoins had necessarily to be of such dimensions and weight to resist the thrust, and the pull of properly-designed gates was comparatively insignificant. Roller-paths and rollers were costly, and both gates and opening appliances were frequently strained to a severe extent by the rollers jamming on obstacles which would otherwise have been cleared.

With reference to the cast-iron tram-plate of the crane-road, the cranes for Preston Dock had been originally specified to have flangeless wheels on the side nearer the dock, so that they could work on the dock-coping, and double-flanged back-wheels to work on 75-lb. flat-bottomed rails. By this arrangement, however, it was impossible to avoid skidding and consequent straining of the pedestals; therefore both wheels were flanged, and now worked on 75-lb. rails laid flush with the coping, the front rail being placed in a specially-prepared groove so as to offer no obstruction. The radius of the cranes at Kidderpur was such that the crane-hook could be brought only to a distance of 6 feet 6 inches from the shed-walls when swung at right-angles to the quay; this involved more swing of the jib than was desirable when dealing with cargoes requiring quick despatch. Each case of the arrangement

of cranes, railway-lines and shedding on dock sides must, no doubt, be considered upon its own merits, but economy of space was important in all cases, and therefore it was difficult to understand why the archway type of crane, spanning one railway track and having the back legs of the pedestal in the 6-foot way, had not been more generally adopted, seeing that where railway lines were a necessity such an arrangement permitted the shedding to be brought about 10 feet nearer the quay than with cranes having solid pedestals. The arrangement as carried out at Preston Dock was shown in *Fig. 4*. Mr. Fowler.

It would be interesting to know what alteration in the design

Fig. 4.



Scale, 16 feet to 1 inch.

of the walls the Authors would think necessary, were the works to be started anew, as a dock-wall which was dependent for its stability on the maintenance of the water at certain levels could hardly be considered safe. The fact that the resultant pressure at the toe of the wall was, under the extreme conditions, more than 4 tons per square foot of bearing-surface, suggested that the design of the wall when once decided upon had not been altered after the treacherous nature of the ground had been discovered, because such a pressure was certainly greater than could safely be imposed upon earth with a natural slope of $7\frac{1}{2}$ to 1. The driving of bearing-piles, or an alteration in the cross section of the wall so

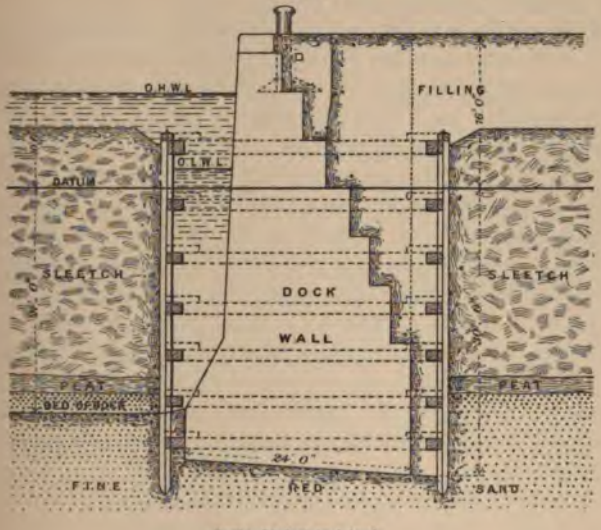
Mr. Fowler. as to increase the base without increasing the weight, or both, would probably have prevented the movement.

Mr. Kelly. Mr. W. Redfern Kelly was of opinion that possibly the greatest mistake which had been made with regard to the Kidderpur dock-walls was that of founding them upon a bed composed of compressible materials. From consideration of the borings, which might, he presumed, be regarded as fairly reliable indications of the nature of the strata underlying the wall base throughout, he had come to the conclusion that, even with the exceptionally wide base of 35 feet, the walls should never have been founded upon such a comparatively soft and yielding stratum as that on which, it would appear, that they had been uniformly laid, namely, peat, mould, and a material which had been described by Mr. Bruce as having, when slightly moist, "resembled putty and behaved much like that substance when the pressure was removed from above it," and which was manifestly insufficient as a resisting medium, seeing that the toe of the east wall yielded vertically to the extent of fully 1·35 foot, and that the walls of the Tidal Basin, and those of the entrance-locks, between it and Dock No. 1 had also sunk to the extent of 3 inches. It would probably have been better, had the designer of the walls adopted the cylinder system; or had a sufficient number of bearing-piles been driven down to the firm sandy stratum, which would evidently have been encountered at a depth of about 25 feet below the wall base, and, instead of distributing the thrust of the wall and backing material over such a large area, to have narrowed the wall base by about 10 feet; and also, instead of constructing a pocket wall, to have made the wall solid and of uniform section throughout, thereby ensuring a more perfect bond than was attainable by the counterfort and void, or pocket system. With a footing, or toe, such as had been provided for in front of the No. 1 dock-wall of 10 feet, and a base of about 25 feet in width, and always provided that the wall base rested upon an unyielding support, such, for instance, as a substantial platform on bearing-piles, driven firmly into the sand, a rake of about 1 foot being given from front to rear of the wall base for frictional resistance, there seemed to be no reason why such a wall should not have sufficient stability, and be suitable to its requirements.

At the Port of Belfast, where the material of the various strata overlying the foundation-level of the walls was in general of an abnormally soapy and treacherous character, being composed chiefly of soft, pulpy, blue clay, alluvial deposit, locally known as "Sleetch" (slightly indurated, or compact mud), a new branch tidal dock had recently been constructed, the walls of

which were founded upon a stratum of fine sand, at a depth of only 5 feet below the bed of the dock; the base of the wall being 24 feet in width, and its height, to the coping-level, 45 feet above the base at the front, and 46 feet above the base at the back, or about the same height as the Kidderpur dock-walls. The water in this dock was tidal, and fell to an average depth of about 14 feet, and occasionally to a depth of fully 16 feet below coping-level; the average depth of water above the dock-bed being 26 feet at ordinary low tide. This wall had been built in an open timbered trench, *Fig. 5*, the sides of which were 28 feet apart in the clear, and the depth of which was about 36 feet. The wall, which was Mr. Kelly.

Fig. 5.



Scale, 20 feet to 1 inch.

built solid, was composed of heavy rubble masonry, with a "random ashlar" facework of granite and whinstone, coped with heavy granite blocks. At a distance of 12 feet back from the coping of the dock, an extensive range of goods sheds had been constructed, in which heavy merchandise was stored, as might be required.

He did not understand upon what principle Mr. Apjohn had assumed, "that the carefully rammed backing would not exert a greater thrust against the walls than that due to a natural slope of 3 to 1;" seeing that he had elsewhere in his Paper stated, that "it is but probable that when the backing caused the movement of the walls, it was exerting a force due to a slope of $7\frac{1}{2}$ to 1," and seeing

Mr. Kelly. that only a small portion of the material shown and described as "Backing rammed in layers," could come within the category of backing, properly so called, or as material exerting a lateral thrust against the wall. All that portion of the filling-in material lying between the vertical at the back of the lowest "set on," and the wall itself, would naturally tend to increase the weight of the wall, and consequently its resistance to lateral thrust. With reference to the value of the resistance offered by the berm which had been left in front of the wall, the condition in which the face of the berm next to the wall had been left when the front timbering had been removed had not been described. It might be that the material would become quite loose, or disintegrated when the timbering of the trench was struck, and unless the space between the wall face and the hitherto consolidated face of the berm had been filled in with sand, or other similarly suitable material, thoroughly rammed and solidified, it could scarcely be expected that the berm would be reliable as a resisting medium, at all events, so far as regarded the forward movement of the wall, at its initial stage. Apart from all other considerations, however, it was a hazardous venture, in view of the yielding nature of the soil in which the works had been executed, to back up the walls without first letting in the water, and thus utilizing it as a counter resistance to the lateral thrust from behind the walls. In all probability, had the water been admitted to the dock to a level of about 10 feet above datum, when the backing operations had been carried up to within about 15½ feet of the coping-level, the works would have satisfactorily sustained the various pressures to which they had been subjected, and to which, in default of that precaution, they had yielded.

In the case of the branch-dock works at Belfast, the water had been allowed to rise in the interior of the dock, following up the backing operations, and the dock excavations, between the walls, had been ultimately removed by dredging, which had been found a much less expensive operation in this case, even where the dredgings had to be taken to sea, a distance of 14 miles, than excavations performed by manual labour in the ordinary way. It might be mentioned, that in the execution of these works, had any softer material than sand been disclosed by the borings, it would have been excavated if found within a reasonable depth, and if at too great a depth from the base of the proposed wall, bearing-piles would have been driven down to the fine sand, and a timber platform erected thereon to support the wall.

r. Robertson. Mr. F. E. ROBERTSON regarded the description of the difficulties

encountered in getting in the foundations of the Kidderpur dock- Mr. Roberts
walls as a better indication of the nature of the soil than was afforded by the sections, Figs. 28 and 29, Plate 2, in which the word "clay" was freely used. He had always considered the expression "clay" was too loosely used in connection with the deposits of the vast alluvial plains of India. These so-called clays were nothing but indurated silt, and he had, during a considerable experience in well-sinking, never met with a sample from the alluvial deposits that would not quickly disintegrate to an impalpable mud when immersed in still water, however hard it might have seemed when first extracted. A real clay, or deposit of a much earlier period would not so dissolve. The expression "clay" should be therefore reserved for material that would, within limits, resist the action of water, and those which disintegrated as described should be classified as silt.

It was curious that in India engineers completely ignored the use of piles, even in cases, such as the Kidderpur Docks, where their use would seem to have been demanded. The expense of carriage was the principal reason for piles not being adopted in works in the interior, but at a sea-port, piles, such as would be used in England, could be landed at about the same prices. It had been suggested that an excavation with pitched slopes, surmounted by a jetty of timber, iron, or brick arching, would involve less risk than a dock-wall; and for use in places where stone for pitching was difficult to procure, the following method, which he had used for pitching banks behind the bridges in a heavily flooded country, offered some advantages. The pitching was composed of brick cubes 1 foot on the side made in the following way. Two slop bricks 12 inches by 6 inches by 3 inches, an ordinary size in India, were moulded on the ground side by side. When stiff enough to bear the weight, but still damp enough to adhere, another pair was moulded crossways over the first, and in the same way two more pairs were added, thus making a cube which could be stacked in a kiln and burnt like ordinary bricks. For this purpose it was, of course, better to burn the bricks to the point of vitrifaction.

Mr. JOHN ROBINSON observed that the dock had been constructed Mr. Robinso
almost wholly in excavation with little embankment. The material, which appeared to have been mostly sandy clay, either wet or moist, was in his opinion incapable of standing at a steeper slope than 3 to 1 whilst its natural slope was $7\frac{1}{2}$ to 1. If the sandy clay and argillaceous sand in the dock and its surroundings could have been drained of some of the water, there would, he

Mr. Robinson. thought, have been no slip. There had probably been a difficulty in drying the material under the circumstances; no mention, however, was made in the Papers of the steps taken with this object, and he should be glad if the Authors would give some information on the point. At Barry Docks [1] sumps had been sunk, 10 feet below the dock-bottom with drains to lead the water into them, from which it was pumped into the sea. Without this precaution some of the material would not have stood at any slope. The filling in at the back of the walls was shown in Fig. 27, Plate 2, to be rammed in layers, but the nature of the material was not stated, and he should be glad to know what had been used. At Barry, hard, dry stone and rocky marl, with fine material for the interstices was well rammed in sloping layers against the back of the walls, and all soft material behind removed. Soft, moist material had been avoided as pressure would have been communicated through it to the walls. Drainage he considered to be of the utmost importance for the successful construction of dock-works. It was also necessary that the filling behind dock-walls for safety should be good, dry, hard material, all soft stuff for some distance back being first removed before the commencement of the trench for the foundations. By such means the bearing area was increased, and the wall protected against undue pressure from moist clay, provision being also made for a firm foundation for either a quay-road or a depôt for stacking goods or merchandise. In some cases it might be advantageous to construct an experimental trench for ascertaining the angle of repose of the material, and how far drainage would improve this angle; also, how much steeper the slope of the excavation might be made than the angle of repose. With this information, and that of the bearing powers of the substrata, the diagram of forces could be drawn with accuracy, and a safe section of wall designed.

Mr. Saner. Mr. J. A. Saner, with regard to the statement in the first Paper that for the protection of the entrance-gates in cyclones and stormy weather a "ship" floating caisson had been provided, while quite agreeing that some provision was necessary in an exposed situation, asked what period of warning would probably be given of a cyclone or storm in those regions. Unless there was sufficient time to float the caisson out of its berth, and place it in position before the storm commenced, it would be practically useless. A caisson of the description given was difficult to fit in its place, and during a storm he did not see how it could be handled.

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[1] Minutes of Proceedings Inst. C.E., vol. ci. p. 129.

Mr. Saner.

If a storm were raging when the water was low the waves would have as much action on the caisson as on the gates, and would cause it to oscillate with great force. If the entrance were so much exposed that the gates needed protection, reversed gates would, he thought, be more satisfactory, though perhaps more costly in the first instance.

In the second Paper the Author stated he had arrived at the conclusion that no further strengthening of the collapsed wall was necessary after the water had been admitted to the dock. He was unable to agree in those conclusions for the following reason. When the dock was empty the thrust of the backing, which had not reached the coping-level, was given as 36·6 tons per lineal foot, the resistance of the "berm" of earth in front was given as 8 tons, and the weight of the wall as 74 tons multiplied by the coefficient of friction, say 25 tons, showing that there were only 33 tons to resist 36·6 tons, and hence the collapse. With the water in the dock 40·8 tons was given as the pressure with full backing, 24·4 tons as the pressure of the water, and 25 tons as the available weight of the wall, making a total weight of 49·4 tons to counterbalance the 40·8 tons of backing. He considered that not only must the backing have contained a large amount of water originally, but that on the filling of the dock the water would find its way through the cracks and further saturate the backing, so that the wall would be practically submerged to within a few feet of the coping. A wall so submerged would lose in weight an amount equal to the displacement of the water, and if this was taken into account the weight on the base would be reduced by 1305·6 multiplied by 62·4 lbs. or 36·3 tons. The result would be therefore as follows: $40{\cdot}8 - \{24{\cdot}4 + (74 - 36{\cdot}3)\,0{\cdot}33\} = 4$ tons, so that the margin was somewhat more on the wrong side than before, and a slight earth tremor would disturb the present equilibrium and cause a further slip. The proper method of securing the broken wall so as to ensure its future stability would therefore have been to fill the pockets up solid with material heavier than "broken bricks" and sand, or, if this did not prove sufficient, to have excavated at the back and either strengthened the wall or filled in with some material so as to relieve it from immediate contact with backing, which at the best could have been little better than sludge.

Sect. II.—OTHER SELECTED PAPERS.

(Paper No. 2847.)

"Long-Distance Levelling."

By Gerald Bagnall.

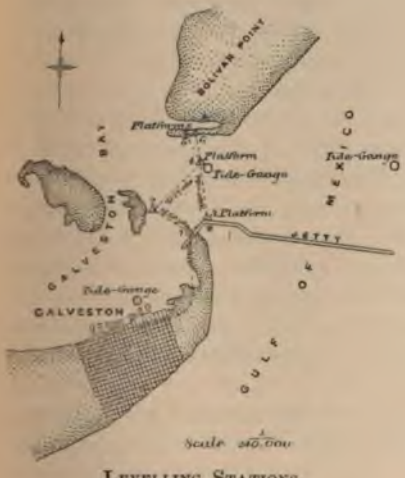
The levelling referred to in this Paper was undertaken to connect the numerous tide-gauges in Galveston Bay, Texas, U.S.A., and test the accuracy of their zeros, which had been obtained by the application of Mitchell's rule[1] to water-levels. As the tide-gauges are situated at considerable distances from the shore, observations of great length had to be taken; and besides these connections between the shore and the tide-gauges, a wide crossing had to be made of the gorge at Galveston, where the depth of the water varied between 6 and 50 feet, and where the bottom was unstable. On account of the strong currents, it was deemed inadvisable to attempt to build platforms in water of greater depth than 12 feet; and consequently it became necessary to take longer sights than had been intended. The first attempts to carry a line of levels across the gorge failed, owing to the destruction of some of the platforms by storms; but, after several efforts, two lines were completed between platforms No. 1 and No. 4, and two lines between platforms No. 4 and No. 6, thus forming two polygons. Some of the results of this work are given in Table I of the Appendix, while Tables II and III show an analysis of a number of sets of observations. This method of demonstrating the possibilities, in long-distance levelling, of showing the peculiar effects of temperature on the instruments, and the discrepancies caused in the results by the direction of the sun's rays, has been adopted as more explicit and concise than a description. The examples have been taken from the data recorded in the field, without selection, and without any rejections or compensations in the reductions. The positions of the different levelling-stations are indicated in *Fig. 1*, and one of the platforms is shown in plan and elevation in *Figs. 2*.

As precision in levelling has advanced, so has dependence on the perfection of instrumental adjustment diminished, and the

[1] Report of the Superintendent of the United States Coast Survey, 1870, p. 98.

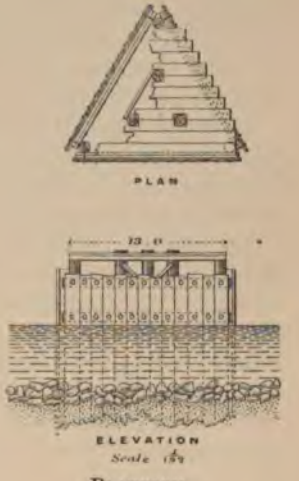
reduction of error by the method of means become more necessary; for while great progress has been made in the construction of the instruments, the standard of accuracy has advanced beyond that degree of precision which can be obtained directly by single physical measurements. Spirit-levelling may be divided into two classes, viz., ordinary levelling for surveys, and "geodetic," or "precise" levelling, where extreme accuracy is required, as in a large triangulation survey or in the determination of water-slopes. The instruments used in ordinary levelling are of the Y or dumpy types, in which dependence has to be placed on instru-

Fig. 1.



LEVELLING STATIONS.

Figs. 2.



PLATFORM.

mental adjustment. In precision levelling, they must be of such form as to allow instrumental errors to be eliminated, or measured by a system of double observations. The difference in the methods of taking and reducing observations in these two classes of levelling, consists chiefly in the manner of treating the excess of the back- over the fore-sights, or *vice versâ*; for in ordinary levelling, since a perfect adjustment of the instrument is supposed to be practicable, there should be no instrumental errors. In precision levelling, on the contrary, the presence of such errors is accepted as unavoidable; and instead of attempts being made to eliminate them by adjustment, their values—called constants—are carefully determined, and a correction proportional to the excess of the back-

over the fore-sights is applied to the result. In the latter class of levelling, owing to the greater accuracy required, corrections are also applied for curvature and refraction where the excess is sufficient to make it expedient. In both these classes of levelling, however, an equalization of the sum of the back- and fore-sights is regarded as the simplest and most reliable means by which to eliminate both instrumental and atmospheric errors; and this is especially so in the case of precise levelling. The method of means for reducing error is not used in ordinary levelling, where each observation consists of a single rod-reading, and where, therefore, the highest standard of accuracy depends on the degree of precision obtainable by direct physical measurement. In precision levelling, on the contrary, this method is employed extensively, both directly and indirectly—directly by taking the mean of several rod-readings in each observation, and indirectly in the determination of the values of the constants.

It frequently happens, in running a line of precision levels, that, owing to the physical conditions of the country, the line cannot be carried forward by short equal back- and fore-sights, as, for instance, when a river or other expanse of water has to be crossed. Under such circumstances, long sights, involving special methods of observation and reduction, become necessary to such a degree that work of that nature has received the distinctive name of long-distance levelling; and it is with this class of precision levelling that the present Paper more especially deals.

Since the limits of error beyond which the results of precision levelling must not extend, are, for the same length of line, generally determined by the objects for which these results are designed, and as consequently these limits of error are fixed independently of the difficulties to be encountered in running a line, it follows that, other things being equal, to attain a certain standard of correctness under more difficult conditions must require the adoption of such methods as would tend to greater precision. In long-distance levelling, therefore, in order to attain the degree of accuracy required in precision levelling, it has been found necessary to advance further in the direction of precision, and to depend entirely on the elimination of instrumental and atmospheric errors by taking simultaneous reciprocal observations. This system, as regards the elimination of instrumental errors, has the same effect as taking exactly equal back- and fore-sights with a single level, and dispenses with the application of corrections to the

result. As regards the elimination of atmospheric errors, the necessity for adopting this method is even greater, as, during the time which is required to take a back- and fore-sight at long distances, a considerable change in refraction may take place, thus causing an error which cannot be corrected with any degree of accuracy. It has also been found necessary to depend more on the method of means, in order to reduce errors of observation; for at very long distances, these errors, while not greater than at short distances as regards the angular value of the deviation of the line of sight from the true level, are yet much larger in actual amount, as indicated by rod-readings.

In the Kern level, used for this work, the telescope is supported on Y's attached to the upper bar, which are closed by means of spring-catches. Detached is a striding level, the tube of which is enclosed in a wooden case. To the ends of this level, metal legs are screwed on, which rest on the pivot-rings of the telescope. Small steel pins project from the extremities of the level case, and pass through notches in the lower side of the spring-catches. The bubble-tube is chambered, allowing the length of the bubble to be adjusted as variations of temperature may require; and it is graduated from the centre towards both ends by marks cut in the glass. The upper side of the level case is covered with plate-glass, above which a mirror is supported in such a manner that the observer may note the position ($\pm$ error of parallax) of the bubble while taking an observation. By raising the spring-catches, the level may be reversed on the telescope; and the telescope may be reversed, inverted, or revolved in the Y's. Those portions of the telescope which rest in the Y's, and which support the level, are called the pivot-rings.

The rods, of various designs used in long-distance levelling, must be provided with a large target. For distances up to 2 miles, a target 1 foot square is of sufficient size. It should be painted red, with a horizontal white streak, $1\frac{1}{4}$ inch wide, across the centre; and it should have a square hole in the middle, to allow the graduation on the rod to be seen. A fine wire stretched across this aperture, in line with the centre of the white streak, enables the rodman to read the position of the target correctly. The rods should be provided with watch-levels to ensure their being held vertically. Both instruments and rods should rest on solid foundations; and if the observations, as is usually the case in this class of levelling, are to be taken across water, the levels should be raised so that the telescope may be about 10 feet above the

surface. This can be accomplished by platforms sufficiently large to accommodate the observer and his assistants, the construction of which must depend on local conditions. If they are built in the water, a protection surrounding them may be necessary to prevent shaking by waves or currents; but in every case the instrument must have a support entirely independent of that portion occupied by the levelling party. *Figs. 2* illustrate a platform built at Galveston in moderately rough water with strong currents, and which gave very good results. In this case, owing to the unstable character of the bottom, it was necessary to place an apron of rubble round it. The corners and the supports for the instrument were heavy piles, driven about 17 feet into the ground, and well braced horizontally and diagonally. Stringers were placed round the outside piles, and rows of sheet-piling were driven along them. This protection, though not entirely preventing vibration, reduced it so much that the only effect apparent was a slight movement of the bubble. This motion was regular and within well-defined limits; and while it seriously interfered with the rapidity of taking observations, it had the compensating effect of overcoming the adhesion of the liquid to the glass, and thus ensured true equilibrium of the bubble. Provision must also be made for a peg, or bench-mark, near each level, at such a distance from it as will allow the height of the instrument to be easily determined. These pegs should be placed as nearly as possible at right angles to the direction of the line joining the instruments, so that the long sights of both observers may be equal.

A long-distance level party should consist of an observer, a recorder, a rodman, a flagman, and an umbrella-man, with each instrument. An assistant observer would expedite the work by watching with field-glasses the signals of the flagman opposite, and conveying their meaning to the rodman near him, thus relieving the observer of the perplexing task of watching and interpreting those signals at the same time that he is giving instructions to his own flagman how to signal for setting his target. In long-distance levelling, simultaneous reciprocal observations must be taken with two levels, one at each end of the line, in order to eliminate the error due to refraction, which has in some instances been found to change so rapidly that the interval of a few minutes between the setting of the targets has necessitated their both being re-set.

The different kinds of errors which have to be eliminated by

this system are: those due to the inclination of the bubble and to collimation (I and C), which are eliminated by each instrument independently; those due to curvature and to refraction (c–r), eliminated by simultaneous reciprocal observations; and those due to inequality of the pivot-rings of both instruments (P_1 and P_2), eliminated by the observers changing stations and repeating the observations. The only error which requires simultaneous reciprocal observations for its elimination, is (c–r), or r alone, as c can be eliminated with a single level. The large amount of work which is entailed by this process is not otherwise wasted, since a great number of rod-readings would have to be taken for the purpose of reducing the mean error. A set of observations at each station consists of four rod-readings, taken with the telescope and level in the following relative positions:— (1) telescope normal, level direct; (2) telescope normal, level reversed; (3) telescope inverted, level reversed; and (4) telescope inverted, level direct. The mean of these observations gives a result with the error due to I and C eliminated.

The difference of elevations of the pegs at the platforms is obtained as follows: The observers having determined the heights of their instruments above the pegs near them, a number of sets of simultaneous reciprocal observations are taken across the long distance in the order above described, the rod-readings being taken only when both observers at the same instant signal their targets to be correctly set. Each observer then, having determined the height of his instrument above the peg near him, and the rod-readings on the peg near the opposite instrument, by taking their difference, obtains the difference of elevations of the pegs $\pm$ (c–r) $\pm$ P, P being the error due to inequality of the pivot-rings (cols. 4 and 5, Table I of the Appendix). Since in the above reductions, (c–r) affects the result of one level positively, and that of the other negatively, the mean of the differences found by both levels gives the true difference of elevations of the pegs, $\pm$ half the algebraic difference of the errors due to the inequality of their pivot-rings (cols. 6 and 7, Table I). When a sufficient number of sets of observations have been taken, the observers change stations and perform the same operations, determining as before the true difference of elevations of the pegs, $\pm$ half the algebraic difference of errors due to the inequality of their pivot-rings (cols. 11 and 12, Table I); but as this error, due to the inequality of the pivot-rings, affects the reduction positively in one case and negatively in the other, it can be eliminated by taking the mean of both

results, which gives the true difference of elevations of the pegs (col. 13, Table I).

The maximum distance at which satisfactory results may be obtained must depend on the kind of instrument used, and the conditions under which the work is carried out. With the Kern level, which has an object-glass of $1\frac{7}{16}$ inch in diameter, a focal-length of $14\frac{1}{2}$ inches, and a magnifying-power of the telescope of 50 diameters, good results can be obtained at distances up to about 3,060 yards, by taking a large number of observations. It is not advisable, however, to take such long sights unless absolutely necessary, as not only do they require many more observations, but also a greater time for obtaining each rod-reading. At distances up to 2,407 metres (2,200 yards), good results may be obtained with comparative rapidity; but the most convenient and advantageous length of sight is about 1,200 metres (1,300 yards). The number of sets of observations required at different distances increases very rapidly with the distance, and depends on the special conditions in each case. Good results have been obtained at 1,945 metres (2,127 yards), with six sets of reciprocal observations, or a total of forty-eight rod-readings (Table I); but this is an exceptional case, as eight to ten sets would usually be necessary at this distance. The time occupied for rod-reading at distances of between 800 and 2,000 metres (875 to 2,200 yards), has been found to range between 4 minutes and 10 minutes when working on platforms in the water; on shore, it would be somewhat less.

Long-distance levelling is affected by instrumental errors, rod errors, errors of observation, personal errors, and errors due to the direction of the sun's rays. Theoretically the instrumental errors are eliminated by the method of taking observations; and in practice this can be very nearly realised by adopting certain precautions. In Table III of the Appendix the changes in the values of C and I are shown in terms of rod-readings, and appear to be due to the effect of variations of temperature on the instrument; but the close agreement of the means obtained by each observer indicates that these errors nearly compensate. Though such large and apparently eccentric variations in the rod-readings might create doubt as to the complete elimination of error, in the Author's experience no serious discrepancy has occurred through this cause; but it has been noticed that the most satisfactory results were obtained when the time occupied in observing each rod-reading was about the same. When the readings are taken at equal intervals apart, the changes due to expansion and contraction will be more nearly the

same between each sight, and therefore should be more thoroughly eliminated in taking a complete set of observations. Bubble-tubes are often not perfectly true, and are also liable to be affected by the temperature, so that a division at one end may have a different value from a division at the other. Errors from this cause may be overcome by always using the same length of bubble, which should be kept in the centre when taking an observation. Another and often a considerable error may be caused, on reversing the level, by changing its position on the rings longitudinally with the optical-axis of the telescope. This is due to there being sometimes a small amount of freedom between the ends of the level and the spring-catches which hold it in place, when, should the rings of the telescope or the legs of the level be at all worn, the error due to inclination of the bubble may not be eliminated by the operations intended for that purpose. It is therefore necessary, if, in the construction of the instrument, provision has not already been made for that purpose, to ensure the level always resting on the same part of the rings. The error caused by this defect may be great in old instruments, in which the rings of the telescope and the legs of the level are often unequally worn by the constant repetition of the operations for determining the value of I and C. The rod errors are the same as in ordinary precision levelling, and are usually small, the most serious being that due to expansion and contraction.

The principal errors of observation arise in determining when the bubble is in the centre, and in setting the target. Of these the former is the most important, for at long distances a very slight error of this kind will materially affect the rod-readings. The bubble should always be kept in the centre while an observation is being taken; and, to ensure its being at a true point of equilibrium, it should be run first from one end, then from the other, and gradually brought to rest at the centre, by means of the micrometer screw under the eye-end of the telescope. The observer can then, by noting the position of the bubble in the mirror, detect any changes while he is setting the target. Before the final setting of the target, the bubble should be shaken up and re-levelled, as an additional precaution against the adhesion of the liquid to the glass. The recorder should also watch the bubble while an observation is being taken; for standing at one side he can detect any motion more easily than the observer from the reflection in the mirror. When working on platforms, if vibration causes any motion of the bubble, precautions against adhesion of the liquid

to the tube are unnecessary; but the difficulty of obtaining a correct rod-reading is greatly increased. The error in setting the target consists in the white streak not being exactly bisected by the middle horizontal cross-wire of the instrument. This is usually a small error when reduced by taking the mean of a number of observations. Personal errors have no special characteristics in this class of levelling, and are the same as in ordinary precision levelling.

Errors due to the direction of the sun's rays are greatest early in the morning and late in the afternoon. When the sun is near its zenith, or when the observations are made nearly at right angles to its rays, these errors have not been detected; but in the morning and afternoon, when reading towards and from the sun, as its rays are more nearly in the direction of the line of sight of one instrument, and at the same time in opposition to that of the other, the difference between the change of the rod-reading of the level in opposition, and the change of the rod-reading of the other level, is an appreciable negative quantity (col. 6, Table III of the Appendix). This, however, is only true within certain limits, for the altitude of the sun must be considered in connection with its azimuth; and results show that between 9 A.M. and 11 A.M., even though the azimuth may be changing more in the direction of the line of sight, yet as the altitude increases the discrepancy decreases. Late in the afternoon similar relative effects have been noticed, but acting in an opposite direction, and consequently causing an increasing discrepancy of opposite sign. With few exceptions, these relative changes in the readings of one rod referred to those of the other seem to follow some law. They are very noticeable in long-distance observations; but owing to the presence of other errors, their values cannot be deduced with any degree of certainty. It is also impossible to determine from the data at hand through what agency the rays of the sun produce this effect; but that they do affect the rod-readings unequally is clearly shown in nearly all the long-distance observations taken under the conditions already described, and consequently there has been no hesitation in constituting such discrepancies a special class of errors. The effect is probably due either to unequal temperature on different parts of the instruments, or irregular refraction and unequal illumination of the targets. As the levels, however, were at all times kept well shaded, it is improbable that their expansion and contraction should be affected more by the direction than by the intensity of the rays; yet such would be the case

were these discrepancies caused by the effect of temperature. The existence of serious errors in the individual rod-readings, presumably due to the effect of temperature, cannot be doubted; but they appear to be eliminated by the methods employed in the work. Table II shows an analysis of three complete sets of reciprocal observations, taken between 9 A.M. and 10.30 A.M., at which hour the direction of the rays has little if any abnormal effect. The differences between the corresponding readings of each set vary both in amount and sign, and appear to follow no law; and, therefore, it may be assumed that they are either due to errors of observation, or are caused by the effect of temperature on the instruments. Errors of observation follow no law, and seldom entirely compensate; while errors due to unequal expansion and contraction of the instrument should be nearly, if not entirely, eliminated by the system adopted in taking these observations. As shown by the means obtained by both instruments, there has evidently been a compensation of error in all the sets, which would hardly be probable were they affected to such an extent by errors of observation; and it seems, therefore, reasonable to attribute these errors to the effect of temperature. This conclusion is further supported by the final results of the work, of which these observations form part (Table I).

While the elimination of error, as shown in Table II, cannot be accepted as positive evidence that errors due to the effect of temperature on the instruments will always compensate, and while it may be, therefore, considered that the unequal changes in the readings of the two rods, under certain conditions of light (Table III), instead of being due to irregular refraction, may be caused by unequal expansion or contraction, yet the elimination of error as shown in Table II is of great importance, since it illustrates how effective for this purpose are the methods employed in taking observations. In cases where the instruments are imperfectly shaded there might be a small residual error, tending to one sign, in each operation of inverting the telescope or reversing the level. The relative changes in the readings of one rod referred to those of the other, in all the series of observations taken before 9 A.M. and after 5 P.M., in levelling from platform No. 1 to platform No. 6 (*Fig. 1*), are shown in column 6, Table III; and while there is considerable variation in the amounts of these changes, probably due in great measure to the presence of other errors, yet the effect of the direction of the rays of the sun is plainly visible. There is but one exception, in a series composed of only two sets of

observations, which were commenced later in the morning than usual. These abnormal changes in the rod-readings were much greater in the forenoon than in the afternoon.

The degree of accuracy obtainable in the results of long-distance levelling would be simply determined according to the usual method of judging results by the amount of the discrepancies between two or more lines, and by their probable error. If, however, the error due to the direction of the rays of the sun be accepted as possible, an element is introduced which can neither be measured nor eliminated with any degree of certainty; and while the results of two lines may agree closely, and the probable error be very small, yet there may be an error of equal sign and amount in both, which will not be apparent in the final results. as indicated in the work between platforms No. 1 and No. 4 (Table I). In this case there are two independent lines, one by way of platform No. 2, and the other by platform No. 3; the difference of elevation found by the former is 779·6 millimetres, and by the latter 780·2 millimetres; the discrepancy, therefore, between the two lines being only 0·6 millimetre (0·0236 inch), and the probable error only about 0·2 millimetre (0·0078 inch). According to the recognized tests in precision levelling, these results would be accepted as most satisfactory; while they appear, from an analysis of the details, to be in error by a much larger amount than is shown by their difference. Column 6, Table III, gives the amounts of the changes in rod-readings in a number of the observations taken in levelling between these platforms; and even assuming that the first set of each of the series was not affected by the direction of the rays of the sun, yet the mean error in these lines, obtained by dividing the algebraic sum of the discrepancies (as shown in column 6, Table III) in each line in the morning observations, less the discrepancies in the afternoon observations, by the total number of sets of observations of both instruments taken across that span under all conditions of light, is much larger than that indicated by the ordinary process of reduction. According to the means thus deduced, there appears to be an error of 1·1 millimetre (0·043 inch) in the line by platforms No. 1, No. 2, and No. 4, and of 1·3 millimetre (0·051 inch) in the line by platforms No. 1, No. 3, and No. 4. As both have the same sign, the mean of the differences in elevation found by them has an error of about 1·2 millimetre (0·047 inch); whereas the probable error deduced from the discrepancy between the two lines, as shown in Table I, is only about 0·2 millimetre (0·0078 inch). This class of error, therefore, while not large in amount, is of a

most serious character, as its presence cannot be detected by the usual methods of reduction, and because it cannot be measured nor compensated for with any degree of certainty; it is also liable to become cumulative in long lines of precision levelling. The only method by which these errors may be eliminated, or reduced in amount, is by repeating the observations in the same direction but under opposite conditions of light.

It is, however, usually much more important to guard against such errors in long lines of precision levelling. Owing to the great length of the lines, the errors, if they be cumulative, will materially affect the results. In ordinary precision levelling, it has been customary for an observer to level over a stretch of ground in the forenoon, and to duplicate his work back in the afternoon. If, however, the line be in about a south-easterly direction, his results will be affected in the same way going and returning; that is, in the morning, the sun being in opposition to his fore-sights, they will read relatively too small, and give too great an elevation; while in the afternoon, the sun being now from an opposite direction, his fore-sights will again be relatively too small, and the elevation too great, thereby seriously affecting the results. In long lines of precision levels cumulative errors constantly occur, which, when analysed, have been observed to follow no single law, and have not been satisfactorily accounted for. In view of this fact, and that in long-distance observations there has been found an error due to the direction of light, which is so small in amount that it could not be noticed in short sights, yet which might become cumulative under certain conditions, it seems that the cumulative errors referred to might be due to the same cause. This theory is suggested, without direct evidence of any connection between the two errors, in the hope that it may lead to investigation, as the Author believes the solution of the causes of many cumulative errors lies in a study of this phenomenon.

The best system by which to determine the height of the instrument is, after having established the peg at as short a distance from the level as will allow the rod to be clearly seen through the telescope, to read it either, as in ordinary precise levelling, by noting the position of the three horizontal cross-wires, and taking the mean of their readings, or by taking the mean of four observations with the level and telescope in different relative positions, as described for long-distance observations. In the former case, corrections must be applied for errors due to inclination, collimation, inequality of the pivot-rings, and for $(c-r)$.

In the latter case, the errors due to I and C are eliminated, so that the corrections to be made are those for inequality of the pivot-rings and for $(c-r)$, all of which are very small at such short distances. It is, therefore, necessary to determine the value at least of the constant P, in order to reduce the observations for the heights of instrument. The value of r can be obtained from the nearest preceding or following set of simultaneous reciprocal observations; but it is so small in amount at very short distances as to hardly merit consideration. If both observers determine the heights of their instruments at the same time, then, in the reduction, as the height of the instrument of one observer is treated as a back-sight, and that of the other as a fore-sight, the error due to $(c-r)$ is eliminated; and the only error remaining is that due to the inequality of the pivot-rings, which is usually insignificant at such distances.

The results that can be obtained in long-distance levelling reach the highest standard required in precision levelling, as may be seen in Table I. The details there shown also demonstrate the necessity of taking a number of observations in order to reduce the mean error, and the importance which this reduction of error by the method of means assumes in long-distance levelling cannot be over-estimated. In ordinary precision levelling, some errors affect the rod-readings so slightly as to be unworthy of special care; and the observer is enabled to pay more attention to the larger errors. In long-distance levelling, on the contrary, there is no source of error which can be neglected. All are of great importance, and a want of care in any of the details may affect the results most seriously. The sources of error, indeed, in long-distance levelling, are not of equal importance in their possible effects; but any one of them is great enough to destroy the value of the results, if proper precautions be omitted. In all levelling, the chief source of error is in the bubble, either by the liquid not coming to a true equilibrium, or by error in reading its position in the tube. The errors referred to are only those which increase in proportion to the length of the sight; and such errors as those due to expansion and contraction of the rods, which are the same in all kinds of work, are not included.

The value of P_1+P_2 can be obtained from Table I, being half the difference between the numbers given in columns 7 and 12, and the refraction $c \pm \left(\frac{P_1+P_2}{2}\right)$ at the different hours is given by half the differences between columns 4 and 5, and between columns 9 and 10. These values, however, are affected by errors of observa-

tion, and by errors due to the direction of the rays of the sun, both of which are of unknown amount.

The rods used on the work were divided only to centimetres, the millimetres being estimated by the observer. The dimensions given for the size of target, and width of streak across the centre, were found by experiment to be suitable for long sights and are arbitrary. The height at which the instrument should be set above the water-surface may vary at different seasons, and in different climates; but 10 feet will usually be sufficient to escape the worst effects of evaporation. Some tests made to determine the plane at which changes in refraction were least variable, led the Author to adopt this height; and it proved sufficient even over the warm waters of the Gulf of Mexico.

The Paper is illustrated by two tracings, from which the *Figs.* in the text have been prepared.

APPEN

TABLE I.—SOME RESULTS OF

Level No. 1, North.						
1	2	3	4	5	6	7
Platform.	Distance apart.	Hour.	Difference of Elevation.		Mean Difference of Elevation.	Mean of all Sets.
			Level No. 1.	Level No. 2.		
	Metres.	H. M.	Millimetres.	Millimetres.	Millimetres.	Millimetres.
2 to 1	1,417	9 0 A.M.	+964·9	+674·4	+819·7	
		9 55 A.M.	+969·4	+672·9	+821·2	+820·0
		10 30 A.M.	+966·2	+671·9	+819·1	
2 to 4	1,945	10 30 A.M.	+234·2	−322·6	− 44·2	
		11 0 A.M.	+246·8	−317·5	− 35·4	− 40·0
		12 0 noon	+241·2	−321·9	− 40·4	
1 to 3	..	..	..	..	..	..
3 to 4	1,884	2 15 P.M.	+164·7	−450·4	−142·9	
		3 0 P.M.	+162·2	−447·7	−142·8	
		3 40 P.M.	+162·4	−438·0	−137·8	
		4 30 P.M.	+139·2	−436·5	−148·7	−141·8
		6 30 A.M.	+129·0	−386·5	−128·8	
		7 30 A.M.	+112·9	−397·5	−142·3	
		8 0 A.M.	+ 96·6	−394·9	−149·2	

DIX.

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LONG-DISTANCE LEVELLING.

Level No. 2, North.

8	9	10	11	12	13
Hour.	Difference of Elevation. Level No. 1.	Difference of Elevation. Level No. 2.	Mean Difference of Elevation.	Mean of all Sets.	Mean of Columns 6 and 11. — True Difference of Elevation.
H. M.	Millimetres.	Millimetres.	Millimetres.	Millimetres.	Millimetres.
4 45 P.M.	+676·6	+985·8	+831·2		
6 0 P.M.	+674·0	+985·4	+829·7	+831·1	+825·6
7 0 P.M.	+676·0	+989·0	+832·5		
7 0 A.M.	−334·6	+224·2	− 55·2		
8 20 A.M.	−321·6	+215·0	− 53·3	− 52·0	− 46·0
9 0 A.M.	−320·6	+225·6	− 47·5		
Difference of elevation of platforms 1 and 4 by first line					+779·6
..	..	..	By levels run on shore		+925·7
5 0 P.M.	−467·9	+147·7	−160·1		
6 0 P.M.	−447·0	+134·5	−156·3		
7 45 A.M.	−422·3	+118·1	−152·1		
9 0 A.M.	−417·3	+115·6	−150·9		
9 30 A.M.	−430·1	+126·7	−151·7	−149·2	−145·5
10 0 A.M.	−409·6	+128·0	−140·8		
10 45 A.M.	−412·0	+130·7	−140·7		
7 15 A.M.	−403·8	+117·8	−143·0		
8 0 A.M.	−415·7	+116·0	−149·9		
9 0 A.M.	−399·8	+106·7	−146·6		
Difference of elevation of platforms 1 and 4 by second line					+780·2
Discrepancy between first and second lines					0·6

TABLE II.—SHOWING CHANGES IN INCLINATION AND COLLIMATION IN LEVELS TAKEN BETWEEN PLATFORMS 2 AND 1 (DISTANCE = 1,417 METRES).

1	2		3		4		5		6	
Number of Observations.	Relative positions of Telescope and Level.		Rod-Readings.		Inclination in Terms of Rod-Readings.		Collimation in Terms of Rod-Readings.		Mean of Rod-Readings.	
	Telescope.	Level.	Level No. 1.	Level No. 2.	Level No. 1.	Level No. 2.	Level No. 1.	Level No. 2.	Level No. 1.	Level No. 2.
			Milli-metres.	Milli-metres.	Milli-metres	Milli-metres	Milli-metres.	Milli-metres	Milli-metres.	Milli-metres.
1	Normal	Direct	1,381·5	2,401·0						
2	,,	Reversed	1,381·5	2,423·0	0·0	$\frac{22}{2}$				
3	Inverted	,,	1,573·5	2,438·0	..	..	$\frac{207·5}{2}$	$\frac{10·5}{2}$	1,485·25	2,417·3
4	,,	Direct	1,604·5	2,407·0	$\frac{31·0}{2}$	$\frac{31}{2}$				
1	Normal	,,	1,376·0	2,372·5						
2	,,	Reversed	1,398·0	2,440·0	$\frac{22}{2}$	$\frac{67·5}{2}$				
3	Inverted	,,	1,587·5	2,458·5	..	..	$\frac{199·5}{2}$	$\frac{31·25}{2}$	1,486·75	2,421·8
4	,,	Direct	1,585·5	2,416·5	$\frac{2}{2}$	$\frac{42·0}{2}$				
1	Normal	,,	1,397·0	2,393·5						
2	,,	Reversed	1,374·5	2,419·0	$\frac{22·5}{2}$	$\frac{25·5}{2}$				
3	Inverted	,,	1,580·5	2,447·0	..	..	$\frac{204·25}{2}$	$\frac{24·75}{2}$	1,487·85	2,418·6
4	,,	Direct	1,599·5	2,415·0	$\frac{19}{2}$	$\frac{32·0}{2}$				

The values of I, column 4, are deduced by taking the difference of rod-readings with level direct, and level reversed, in each set.

The values of C, column 5, are deduced by taking the difference of the means of rod-readings with telescope normal, and telescope inverted, in each set.

TABLE III.—SHOWING CHANGE IN ROD-READINGS.

1	2	3	4	5	6
Station.	Time of Observing.	Distance between Platforms.	Change in Rod-Readings of Level, Sun moving in opposition to Level.	Change in Rod-Readings of Level, Sun moving in direction of Level.	Algebraic Difference of Columns 4 and 5 = Abnormal Relative Change of Rod-Readings of Column 4.
	H. M. H. M.	Metres.	Millimetres.	Millimetres.	Millimetres.
4 to 5	5 15 P.M. to 6 30 P.M.	981	−22·2	−10·6	−11·6
3 „ 4	5 0 P.M. „ 6 30 P.M.	1,884	−20·9	−13·2	− 7·7
1 „ 2	5 25 P.M. „ 7 0 P.M.	1,417	+ 0·4	+ 3·2	− 2·8
4 „ 6	5 15 P.M. „ 7 0 P.M.	967	− 5·0	+ 6·0	−11·0
3 „ 4	7 45 A.M. „ 9 0 A.M.	1,884	− 2·5	− 5·0	+ 2·5
3 „ 4	7 15 A.M. „ 9 0 A.M.	1,884	− 1·8	+11·9	−13·7
2 „ 4	7 0 A.M. „ 9 0 A.M.	1,945	−14·3	+ 1·4	−15·7
3 „ 4	6 30 A.M. „10 0 A.M.	1,884	−32·4	+ 8·4	−40·8
4 „ 5	7 0 A.M. „ 9 20 A.M.	981	− 0·8	+10·0	−10·8

(*Paper No. 2876.*)

(*Abridged.*)

"Railway Construction in the Philippine Islands."

By WILLIAM LIDDLE, Assoc. M. Inst. C.E.

THE Philippine Archipelago is situated between 4° 45′ and 21° of north latitude, and 117° and 126° 30′ of east longitude, and consists of some 600 islands, only eleven of which are of importance. The principal one is Luzon, whose chief town, Manila, is also the capital of the Archipelago, and the centre of the Colonial Government. The city and suburbs contain about 300,000 people, 200,000 of whom are native Indians, 40,000 Chinese, 5,000 Spaniards, 54,000 Spanish and Chinese half-breeds (known as Mestizos), and 1,000 English, German, and other foreigners. The whole Archipelago has since 1764 been the undisputed property of the Spanish crown.

The general character of the islands, and especially of the civilized parts of Luzon, is of exceptional fertility. Rice, sugar, hemp and tobacco are the principal products, the three latter being, with sapanwood, the chief exports. In 1889 the exports were: sugar, 218,925 tons; hemp, 71,071 tons; tobacco, 11,247 tons; sapanwood, 4,592 tons.

Rice of late years has not been grown in sufficient quantities to support the native population, and the deficit has had to be imported, principally from Saigon. It is considered, however, that the improved means of transport afforded by the Manila-Dagupan Railway, which passes through Pangasinan, the greatest rice-growing province in the Philippines, will enable local growers to put larger tracts of country under cultivation, and by that means, combined with cheaper production, render the import of rice unnecessary. There are large tracts of fertile lands everywhere to be found idle, only waiting the advent of railways to enable them to put their produce on the market. Coffee of a very superior quality, indigo, maize, cacao, and cocoa-nuts are also grown. The hard woods of the Philippines are also of great importance for engineering construction and shipbuilding, and large quantities have been exported for the building of piers, &c., in China.

Manila, in addition to being the centre of the Government, is also the commercial capital of the Archipelago, and is, besides Iloilo and Cebú, the only port where a Custom House is established. The city is situated at the mouth of the River Pasig, which is accessible for vessels drawing 13 feet. On the south side of the river, docks have been in course of construction by the authorities for some years, but practically nothing has been done. The bay affords anchorage for the larger steamers whose draught is too great to permit of their crossing the bar and anchoring in the river. Dagupan, the present northern extremity of the railway, is situated on the banks of the River Horno, at about 2 miles from its mouth, where it enters the Gulf of Lingayen. It has been the port from which the rice and other produce of the province of Pangasinan have hitherto been conveyed by coasting craft to Manila. Spanish is the official language, but is very little understood by the class from which the native workmen are drawn. Along the line of railway there are four distinct languages, viz., Tagolog, Pampanga, Ilocano, and Pangasinan.

All over the rich band of cultivated country between Manila and Dagupan are numerous villages, with a population estimated at about 1,500,000 people. The great drawback to the further development of the country has been the want of economical internal communication. To remedy this the Spanish Government in October, 1886, granted a concession, with a guarantee, for the construction and working of the Manila-Dagupan Railway, a single line of 3 feet 6 inches gauge. The railway was, with the exception of the slip-way at the Government Arsenal at Cavite (designed and built by Mr. James L. Houston, Assoc. M. Inst. C.E.), the first engineering work of any magnitude and importance ever carried out in the Philippines. The length of the line as actually built is 121¼ miles. It was not until March 1888 that construction was actually commenced, and then the progress made was very slow, due amongst other drawbacks to the fact that the natives had to be educated to the work.

Other difficulties arose: the expropriation of land caused delay, the transport of materials for construction was unsatisfactory and expensive. The native draught animal is the "Carabao," or water buffalo. It is slow and can work in the hot sun for only two hours or three hours at a stretch. The loads it is able to draw through the soft earth in the wet season are very small. Sickness also was a factor to be reckoned with. An epidemic of Asiatic cholera broke out in April, 1889, and it was not until the August

following, that the Port of Manila was declared clean. A number of the construction staff, including Mr. W. H. Scott and Mr. Sidney Pollard, Assoc. MM. Inst. C.E., succumbed to the disease. In September, 1889, it was seen that the transport of materials on the works would require to be improved. Accordingly a strong effort was made to get the permanent way laid throughout with as little delay as possible, but this was frustrated for a time by the want of sleepers. Arrangements had previously been made with natives and others for the delivery of large quantities, but it was quite clear that very few, and these of only questionable quality, would be supplied. Thereupon arrangements were made with a reliable English firm of timber merchants in the southern part of the island for a large and immediate supply cut from the best woods, and, soon after, a contract was made for a further supply from Sandakan in Borneo.

Rails and fastenings had arrived in satisfactory quantities from England, so that when the dry season set in, in January 1890, the construction of the railway was proceeded with energetically and economically. As many as 12,000 native and Chinese workmen were at one time employed, and by the end of that season 102½ miles of earthwork had been completed, and all land transport was conducted by means of contractors' tank locomotives. Temporary bridges were built where necessary over rivers, and over the sites of land openings. As a rule, the former were built on the centre line of the permanent structure, and proved very useful in the erection of the wrought-iron superstructures. The temporary bridges over the land openings, of which there were a great number, varying from 1·50 metre to 10·00 metres in clear span, were so arranged that the abutments and wing walls could be built up to the level to receive the wrought-iron superstructure, without interfering with the construction traffic. When all the land openings on a stretch of, say, 10 or 15 kilometres of railway were sufficiently advanced, arrangements were made by which traffic could be stopped on that section for such a length of time as would allow the superstructures to be erected. When traffic was resumed, usually the permanent locomotives, weighing 32¼ tons, were employed, and the lighter locomotives moved on ahead. The object always kept in view as of paramount importance, was to have a line of railway through from one end to the other, even if only good enough to carry a trolley. Rail-laying was carried on from both ends, and from one intermediate point in both directions. The permanent-way materials were conveyed from Manila (where, owing to the customs regulations, all material had to be

landed), to Dagupan in coasting craft engaged in the rice trade, as ballast at prices varying from $1·00 to $1·50 per ton.[1]

To several intermediate points on the railway, materials were carried over the creeks, which are very numerous between Manila and San Fernando, by means of "cascoes" or small lighters, drawing up to 20 inches and carrying about 25 tons.

Survey and Location.—The survey, owing to the flatness of the country and the fact that the concession made it obligatory to pass through certain towns, was reduced to a very simple matter. As a rule long straights were found as economical as short ones and curves. The sharpest curve was of 20 chains radius, but most of the curves were of 50 chains radius. The gradients were all very easy, the sharpest being 1 in 122·4 for ¾ mile. There were several long lengths—one nearly 9 miles—horizontal. All station-yards were on the level and straight, and, when practicable, a convenient length of straight was put in at both ends of bridges and stations.

Fencing.—The line was fenced on both sides with live fencing. The plants usually employed were the *Madre de Cacao* and the bush locally known as *Tuba-tuba*, both of which, in the course of under a year, produced a tall, thick, and fairly substantial fence. A horizontal rail of bamboo was occasionally introduced to support the plants.

Earthworks.—Ninety-three per cent. of the railway was on embankment made from side ditches, which had a constant depth of 1·00 metre, and a varying width. The embankments were 4·00 metres wide on the top, with 1½ to 1 side slopes, *Fig. 1*, and

Fig. 1.

Scale $\frac{1}{100}$. The dimensions are in metres, indicated by *m*.

MANILA-DAGUPAN RAILWAY.

owing to the manner in which the earth was put into them—usually with a kind of basket—a high percentage, varying between 15 and 33⅓, had to be allowed in the height for consolidation. The piecework was paid for by lump sum per chain length, so as to avoid questions of measurements, which would have provided a rich harvest for the native lawyers. Several serious "wash

[1] Mexican (silver) dollar, worth then about 3*s*. 4*d*., but now much less.

outs" were caused by the heavy tropical rains acting on newly-made banks, and by floods.

Owing to the flat nature of the whole district and the heavy rainfall, which averages 2 metres annually, falling mostly between June and November, heavy floods were frequent. No reliable data being obtainable as to the maximum flood-levels, at one or two places the embankments had to be raised and additional water-ways built. Vegetation developed with tropical rapidity on the slopes of the embankments and assisted materially in protecting them. The average cost of forming the embankments, including allowance for settlement, was 13 cents per cubic metre.[1] No difficulties were ever experienced in procuring sufficient native labour.

Permanent Way.—The rails were of steel, flat-bottomed, and weighed 45 lbs. per yard. The sleepers measured 5 feet 11 inches × 8 inches × $4\frac{3}{4}$ inches, and were spaced at the rate of nine sleepers to a 7·00-metre rail. With the exception of 25,000 brought from Borneo, they were all of native woods. It was found that the white ants did not attack sleepers when the road was in constant use, but that when laid in a siding—for example, into a ballast-pit which was disused for several months—they were almost completely eaten away. They were adzed to an inclination of 1 in 30 and afterwards bored by machinery. A Bessemer-steel chair plate, weighing 5·8 lbs., was inserted between the rail and the sleeper, at the joint sleepers, and at the centre sleeper of each rail. The ballast was mostly coarse sand found on the line of railway and in the beds of rivers during the dry season. At the commencement an attempt was made to obtain gravel ballast by dredging from the beds of the rivers, but it proved costly, and the ballast could only be obtained at a slow rate. The leads were in some instances long, amounting in one case to nearly 43 miles. Notwithstanding this, the cost per cubic metre, including lifting and lining the road, was under $0·50.[2]

Bridges and Culverts.—The absence of any suitable building-stone on or near the line of the railway, led to the adoption of Portland cement concrete, faced with brickwork, for the construction of the abutments and wing-walls of all the land openings. Owing to the prevalence of earthquake-shocks the use of arches was unadvisable, and the superstructure of all bridges was therefore of wrought-iron girders. The foundations of the land-openings were, as a rule, carried down to about 20 inches below the

[1] About 4*d.* per cubic yard, at 3*s.* 4*d.* per dollar.
[2] About 15·3*d.* per cubic yard, at 3*s.* 4*d.* per dollar.

bottom of the adjoining side ditch, when usually a satisfactory foundation was obtained. In one or two instances, however, where the foundations were in soft ground, a greater depth had to be proceeded to, and a foundation prepared by using piles of an excellent local timber driven all over the area of the foundation at about 16 inches centre to centre.

The foundations of the river bridges, especially between Manila and San Fernando, were a source of great trouble and expense. Immediately the thick surface crust of vegetable earth and loam was pierced, a bed of fine black semi-liquid mud was found of varying thicknesses. This bed is one of the chief difficulties in the construction of the Government port works in Manila. The abutments and piers of the river bridges were constructed of cast-iron cylinders, two rows to each pier and abutment. The cylinders were each 6 feet in external diameter and $1\frac{1}{4}$ inch in thickness of metal, in lengths of 6 feet, and in three segments for the sake of economy in shipment and facility in handling. The cutting-edge lengths were, however, cast in one piece. There were in all eighty-eight cylinder piers to be founded either in or below the mud. In some instances the mud was passed through at a depth of from 16 to 20 feet below the level of the banks of the river, and a bed of hard blue clay met with into which the cylinders were sunk from 6 to 10 feet; in other cases the cutting-edge had to be carried down nearly 80 feet without reaching any foundation sufficiently resisting without the assistance of skin friction. Experiments were made which showed the skin friction to amount to 3 cwt. per square foot, but this was not always to be relied on. In fact, the behaviour of the cylinder piers during the process of sinking was most erratic. On one occasion a cylinder stood loaded with 50 tons of rails through a severe earthquake-shock without any movement; yet a few days afterwards it descended, without any warning, over 10 feet, and only stopped when the rails rested on the adjoining staging.

After some experience had been gained, it was the practice to load the cylinder, after it had entered a bed of clay of comparative hardness and the cutting-edge was sufficiently deep to remove any risk of scour, with 100 tons of rails, and allow it to remain so for seven days. If in that time no further sinking had taken place, the concreting was proceeded with until it reached the level of the bottom washers of the holding-down bolts. The cylinder was then again loaded with 100 tons for seven days and usually sank from $\frac{1}{2}$ to $1\frac{1}{2}$ inch. The greatest load that can ever come on the top of the cylinder piers is 115 tons per pier.

In the early days of the cylinder-sinking it was considered necessary to keep the cylinders free of water by pulsometer-pumps, but, as the progress made was slow and the cost heavy, the mud or clay was afterwards simply dredged out by a Priestman's grab, and a native diver was sent down periodically to regulate the cutting-edge. This method of sinking was found not only to be cheap but expeditious, most of the time occupied being taken up in the construction of the staging and in the testing.

There were in all twenty-four river bridges, for twenty-three of which the piers were 71 feet, centre to centre, and the clear span of the openings 65 feet. At first the girder bedstones were made of marble from the Montalban quarries, but owing to its great cost and the uncertainty of its supply, girder beds of Portland cement concrete, composed of one volume of cement to four volumes of coarse sand, were mostly used. The bridges were designed for a live load of 4·50 tons per lineal metre (1·37 ton per foot) for spans of 10 metres and under, and for spans of over 10 metres, 4 tons per lineal metre (1·22 ton per foot). With the exception of three of the 71-foot spans, all the wrought iron and steel was manufactured at Hal, Belgium, and all the cast-iron cylinders were made at Paisley.

Bridge over the Rio Grande de la Pampanga.—The river of this name is one of the largest in the Island of Luzon, and is crossed by the railway at 28½ miles from Manila. At the point of crossing, the river is 492 feet in width, and tidal, the maximum range of tide being 3 feet. The bed of the river consists of black silt overlying mud, and is so easily penetrated that on one occasion a bore was put down 114 feet in ten hours.

In the early part of 1889 a bridge of seven spans, similar to the twenty-three above mentioned, was designed and the construction proceeded with until nearly all the cylinders were sunk, when a flood of greater severity than usual destroyed most of the piers. One pier was completely thrown over. It was then decided to abandon the original design, and the Author advised a single-span bridge of 492 feet. This, however, was not agreed to, and a continuous girder bridge, having a centre span of 192 feet and two side spans of 150 feet each, was shipped from Europe. But continuous girders were, owing to the unreliable nature of the foundations of the supporting points, and to the prevalence of earthquakes, quite out of the question. Permission was obtained from the Government engineers to convert the continuous girders into independent girders. This, and the fact that the continuous girders had been designed for a less live load than 4·00 tons per

lineal metre, necessitated the addition of a large quantity of wrought iron to the flanges and bracing of the main girders.

The wind-pressure was taken at 55·3 lbs. per square foot with the bridge unloaded. Six kilogrammes per square millimetre (3·71 tons per square inch) was assumed as the limit of safe working stress of the ironwork, rivet-holes being deducted. The total weight of the wrought-iron superstructure, including the weight added to convert the continuous girders into independent girders, was 351½ tons. The foundations of the two centre piers were the source of a great deal of trouble and expense, the caissons sent out from Europe being much too small in area. In September, 1891, the Author proceeded to Hong Kong and made arrangements with the Kowloon Dock Company for the building of new bottom lengths for the caissons of the two centre piers, and as time was of great importance these had to be designed to suit the plates, angle-irons, &c., in stock. The outside dimensions were 47 feet by 18 feet and the ends semicircular. The similar dimensions of the caissons sent from Europe were 42 feet by 13 feet, so that the supporting area of the foundations was increased by more than one half. The height from the cutting edge to the junction with the original caisson was 19·7 feet. The weight of these new bottom lengths was 43½ tons each, and they were each shipped in eight pieces. They were fitted with a false bottom of timber 10 inches thick, launched into the river, and floated to their permanent position. They were sunk by Priestman's diggers worked by 5-ton steam-cranes on barges. During the sinking, the water-level inside the caisson was maintained as nearly as possible at the water-level in the river, so as to keep the walls of the caisson in equilibrium. Difficulties arose through the cutting edge meeting with the staging of the abandoned bridge, and the northern caisson was on several occasions tilted out of the vertical.

The caissons were divided into three wells by two cross walls of brickwork in Portland cement mortar, resting on wrought-iron girders united to the cutting edges. The walls were carried up as the sinking proceeded, five or six days being allowed for the work to set before resuming the sinking. The side walls were composed of a third of their volume of brickwork and two-thirds of Portland cement concrete, the facing and bonding courses, placed 1 metre apart, being of brickwork. Indents were left in the brick facing to bond in with the concrete filling of the caisson. The caisson for the south pier was carried down to a depth of 83 feet 8 inches below the bed of the river, and that of the

north pier to a depth of 84 feet 6 inches. The cutting edge passed through 59 feet of silt and mud, 16 feet of plastic brown clay, 3 feet of sand and clay, and then a very firm bed of sharp brown sand, into which the cutting edge was sunk about 5 feet 9 inches. In the bottom of the foundation of the northern pier a spring of sulphurous water was found, having a temperature of 15° F. above that of the river. The spring was conducted to the surface by a pipe. The pressure on the bases of the foundations was calculated at 5·39 tons per square foot, no deduction being made for skin friction, but including the weight of the earth supported by the shoulders of the caisson. The natural pressure on the ground at the bottom of the foundation, due to the weight of water in the river and the weight of the superincumbent earth, was calculated at 4·48 tons per square foot. Assuming that the firm bed of sand in which the cutting edge rests was incapable of supporting more than its natural pressure, then a skin friction of 186 lbs. per square foot would be required to support the weight of the pier with its proportion of dead and live load. The wells of the caissons were filled with rubble concrete, of which material the upper parts of the piers were also built. The exposed surfaces of the piers and abutments were faced with concrete blocks. The girder-bed stones were of Hong Kong granite. The superstructure was erected on the north bank of the river in line with the centre line of the bridge and launched out. The greatest progress made in any day was 88·6 feet.

The Table below gives the prices of the chief items of expenditure on the works :—

PRICES OF LABOUR AND MATERIALS

(in Mexican dollars, worth 3*s.* 4*d.*, on the average, when the railway was under construction).

Excavation in railway cuttings, lead 50 metres, loam or vegetable soil, or sand	$0·17 per cubic metre.
Ditto from side ditch put into embankment, vegetable earth, loam or sand	$0.11 ,,
Ditto from side ditch put into embankment, wet stiff clay with strong grass roots	$0.37½ ,,
Ditto in foundations of bridges (land openings) and culverts	$0.16½ ,,
Making and putting in concrete	$1.25 ,,
Labour, building brick-facing	$3·25 ,,
Gravel dredged from river-beds	$0.75 ,,
Labourers	$0.25 to $0.37½ per day.
Bricklayers	$0.50 to $0.62½ ,,
Riveters	$0.37½ per day.
Blacksmiths	$0.62½ ,,

Telegraph.—Three lines of wires were erected, two being for the use of the State and one for the service of the railway. The posts originally erected were hard-wood poles supposed to be proof against white ant. After a few months, however, it was found that many of them were being rapidly eaten away at ground-level by the white ant. Every strong wind brought down kilometres of line. Living cotton trees were then tried and proved a great success. They cost $0·75[1] each, including planting and six months' guarantee, whereas the hard-wood poles cost from $1·40 to $2·00 each[2] delivered only. Morse ribbon instruments were used.

Stations.—There were in all twenty-seven stations, namely, one first class (Manila), two second, three third, twenty fourth, and one special goods station. The buildings were of a most elaborate and costly description, and represent a large sum of money spent without in any way increasing the earning capacity of the line. The designs of these buildings were, however, set forth in the Concession.

Earthquakes.—The Philippines have been called "The home of the earthquake and typhoon," and during the construction of the railway there occurred several exhibitions of both phenomena.

The first earthquake shock experienced was on the morning of May 21, 1889, but as little work had been then executed, no damage was done. The second severe shock occurred on March 16, 1892, at 9.15 P.M., and increased in severity towards the northern or Dagupan end of the railway. Between mile 99½ and Dagupan nearly the whole of the Government buildings, convents and churches were more or less destroyed, and several lives were lost. In the town of Dagupan great damage was done, nearly half the houses being destroyed. The railway bridges in this district suffered very little, and there was no interruption to the construction traffic. Had the line been open to the public there would have been no delay in the train service. At mile 101 the embankment sank gradually in a regular curve for about 9 chains to a depth of 2 feet at the centre, and at mile 112 the line was displaced horizontally. The south abutment of the two-span bridge over the Malabago at mile 116⅔ sank 11 inches, and was moved forward 19 inches, the centre pier and north abutment remaining unaltered. The whole of the station-yard on embankment at Dagupan, including the buildings which were well founded into the solid ground, sank 4 inches.

[1] 2*s.* 6*d.*, at 3*s.* 4*d.* per dollar. [2] 4*s.* 8*d.* to 6*s.* 8*d.*, at 3*s.* 4*d.* per dollar.

In Pangasinan, daily up to the following December, numerous shocks were experienced, but none of any serious nature.

Testing of the Works.—Before any section of the railway could be opened for public traffic it had, under the terms of the Concession, to be inspected and tested by the engineers of the Government. The whole length of the bridges was covered with locomotives loaded with a full complement of coal and water, and as these did not bring the live load up to the weight set forth in the technical conditions of the Concession, additional weight in the shape of rails, bags of sand, &c., had to be added. Observations were taken very accurately before and immediately after the application of the load at the ends and centres of each main girder. The load was left on for at least eight hours and then another set of similar observations was made before and immediately after the removal of the load. The settlement, if any, of the points of support of the girders, the deflection of the main girders and the extent of their recovery were thus ascertained. A few curves were then tested for radii and uniformity, and likewise a few of the gradients levelled over. The velocity tests consisted in first running a train composed of two locomotives, loaded with a full complement of coal and water, a number of wagons, loaded to 10 tons each, on four wheels, sufficient to cover the longest bridge, and a brake-van, over the line, at a speed of 18 miles per hour, alternately applying and releasing the brakes whilst crossing the bridges. The way and bridges were then carefully examined for injuries and defects. The same train was then run over the line at a speed of from 25 to 30 miles per hour, usually the latter, and the way and bridges again examined.

The Paper is accompanied by photographs, a map and nine tracings, from one of which the *Fig.* in the text has been prepared.

(*Paper No. 2658.*)

"Dry-Dock Equipment, and Ship-Repairs."

By Joseph Fell Redman.

The increase in size and in value of merchant steamers has rendered their rapid and efficient repair in a dry-dock of great importance, especially in the case of mail-steamers. The mechanical appliances of a dry-dock are frequently in so primitive a state that, if possible, repairs are sent to the workshop, as better results are thus obtained both as regards time, quality, and cost.

The draught of some of the largest steamships built within the last twenty years, in average dry-docking state, ranges between 17 feet and 23 feet, so that a depth of water of 25 feet on the sill is required to allow a margin for varying tides. However, even 25 feet of water would not meet all emergencies, as an ordinary load-draught of mail-steamers is 26 feet; and, as in taking a ship out of dock a propeller-blade may be broken, time and money would be saved by partially drying such a ship down to the top of the boss, extra shores being placed round the vessel, and, as a further precaution, the rise of floor being known, an extra line of blocks on each side of the keel along the flat portion of the bottom. The Author once docked a loaded steamer, drying her from the mean draught of 19 feet 2½ inches, with 7,300 tons displacement, to 12 feet with 4,060 tons, so that the weight on the blocks was 3,240 tons. The displacement of this steamer, at 11½ feet mean draught, with clean-swept holds and no coal or water-ballast, is 3,850 tons, so that less strain was imposed upon the hull than by an ordinary docking. Two new propeller-blades were fitted; and the vessel proceeded to sea in thirteen hours from the time of entering the dry-dock. On the other hand, the Author has seen a vessel delayed many days by the discharge and replacement of 1,800 tons of cargo. The vessel was tipped 29 feet 5 inches fore and 11 feet 4 inches aft, and one blade was fitted. When a dry-dock is available, the tipping of a loaded steamer is inadvisable, as it is dangerous and expensive, according to the nature of

the cargo. The Huskisson Lock in Liverpool was often used as a dry-dock some years ago; and it has consequently occurred to the Author that at docks, having more water on the sills of their entrance-locks than dry-docks, some low blocks might be fitted with great advantage. A timber rubbing-fender, 12 inches by 12 inches, at each side of the lock, would suffice to support the shore-ends.

Docking a Ship.—The vessel having been towed to the dry-dock entrance, is hauled into position by ropes, and steadied over the line of blocks. For hauling the vessel upright, masthead tackles of 5-inch wire-rope, coupled by wire strops and shackles, and led to a secure anchorage, are useful but objectionable. It is better to present the vessel plumb for docking. Free bilge-water, which the pumps cannot clear, often causes a vessel to lean to one side; and after being dried out, and all wear and tear of cement-work made good, the vessel comes out quite stiff. With pumping-power capable of emptying a dock in about 2½ hours, it is desirable to have four rafts on which the men can scrub and scrape the vessel's hull as the water descends; and when a ship is very foul, the pumps have to be eased or stopped. Rotary wire-brushes, and jets of water, under a pressure of at least 100 lbs. per square inch, may be useful. Ashes, ground-clinker, or sand, with either steam or water from an annular jet, would enable a vessel to be scoured bright.

The fixing of the shores as the water leaves seems a simple operation on a calm day; but four hydraulic shores, on each side of a ship, placed in position in pairs, would be useful in a high wind or with a quickly-falling tide, *Fig. 1*, p. 186. The hydraulic cylinders could be built into the side-wall, at about the level of the upper altar; and the ordinary shores would rest in a rebate forming the ram-head.

A large steamer approaching an entrance in a strong wind or tideway, is controlled by a 7-inch manilla head-rope, with a breaking-strength of about 25 tons, and a similar rope at the stern. If either rope breaks, there is not time to pass another to the tug or to the shore before the vessel swings round heavily against a pier-head or boom. With a floating hydraulic-buffer in rear of the boom, to project and meet the approaching vessel, it might be eased up and brought alongside quietly, when a fresh rope could be made fast and the vessel warped in. This appliance would be most useful for twin-screw steamers, or single-screw steamers of fine lines aft, with counters running too high above the quay-walls of the entrance for the use of ordinary fenders.

Blocks and Blocking.—In most dry-docks, when a vessel dries, the whole of her weight rests upon the keel-blocks, until a row of shores can be fitted between her bilge and the dock-bottom. Sliding bilge-blocks, as at present fitted, involve too much rigging for drawing them into position; and they hinder the painting and examination of a ship's bottom. The sliding bilge-chocks in the dry-dock of the North German Lloyd Co., at Bremerhaven, moved upon balks of timber 10 feet apart, so that it was necessary to pass round the ends, or climb over them. In the Erie Basin dry-dock, Brooklyn, New York, the dry-dock bottom is left flush, as the chocks draw back over metal races, into recesses at the sides of the dock. To avoid undue crushing of "caps" under the engines or any local weight, extra blocks can be laid at such points. At some ports the dry-dock is pumped out between the turning out of one vessel and the docking of another, for the purpose of laying fresh fir-caps. This seriously reduces the working capacity of the dry-dock; but any irregularity in the keel will readily adjust itself on the fresh soft caps. With good English-elm caps, when bringing in another vessel on the same tide, no great risk is run, as before lifting the first vessel the state of the blocks can be ascertained by inspection.

Good blocks for the heaviest class of work are shown in *Fig. 3.* Other blocks, which have stood hard work for many years at the Thames Ironworks, and are readily removed, are illustrated in *Fig. 4.* The block under the cap is strengthened by bolts passing through it with three plates on each side, to resist crushing strains. These blocks are not bolted to the dock-bottom, but are braced together in groups of three and loaded with double-headed rails. The blocks wear most quickly at the springing of the fore-foot from the straight line of the keel, corresponding to the position of the foremast in many modern vessels, as no shores can be fitted under the stem until the vessel is dried out. With single-screw steamers, floating considerably by the stern, and not having much rise toward the heel of the stern-frame, it is better to leave the caps off the last two blocks, and subsequently make up a bearing by folding wedges. With a tender vessel, no weights should be shifted, either vertically or athwartship, without due provision being made by shores; and such weights should be replaced before the vessel is refloated.

Some vessels need water-ballast for dry-docking, and while in the dock the tanks may be emptied for cleaning, examination, and cement-washing. For undocking, there is considerable risk and delay if the water is let in to about the 8-foot water-line and

stopped until the tanks are filled. Sometimes the filling of a small tank, holding about 100 tons of sweet water, directly the vessel was cleaned, has saved a day's dock rent; but it would be a convenience to have a large supply of coarse water available from a 6-inch hose. This water would be good enough for washing out limbers, and also for washing the cables as they are lowered and ranged on the dock-bottom for examination and overhauling the shackle-pins.

Dry-Dock Bottom.—A flat bottom for a dry-dock, cambered slightly towards the gutter water-ways on each side, with a raised pathway round, as in *Fig. 1*, gives space for passing round a vessel before the dock is quite dry; and a reflected light enables any defect to be quickly observed. All ring-bolts, &c., should be flush on the dock-bottom. Ring-bolts, of 1½-inch round iron, are convenient for fastening tackle-blocks to for work near a ship's stern, when placed 10 feet on each side of the keel-blocks, and about 10 feet apart. For checking draft-marks and truth of keels, datum-points of granite on the middle line of the dock, about 25 feet apart, would be useful; or small bronze castings could be fitted in any existing dock, and proved by sights from time to time. A tramway on each side of the dock, with a trolley spanning the water-ways, would render one slide at the head of the dock sufficient, coupled with a hydraulic hoist, as shown in *Fig. 1*; and these tramways would save wear and tear of the dock-bottom and altars.

Staging and Painting.—In London, the staging for painting and propeller work, charged at 23*s.* per 100-foot run, making and breaking, forms a costly item. Upper stages are carried by tiers of shores, and must be two planks in width; lower stages are carried efficiently on iron horses. If no extensive repairs are necessary, the largest vessels are dry-docked and turned out after receiving two coats of paint, one priming and one composition, or two coats of some anti-corrosive material, within twenty-four hours, saving a second day's rent. In some states of the weather the bottom has to be dried artificially by portable fires; but without care these give trouble. Gas fires, with atmospheric burners, could be readily passed under the bottom, and, if of good size, should dry it quickly. They should be kept at least 3 feet from the plating, and be moved continually to avoid local heating of the plates. Owing to the speed of painting required, much paint is wasted. The Author has suggested that it should be applied with a squirt, the feasibility of which has since been confirmed by the spraying nozzle used in the Priestman petroleum

engine, and also by the statement that the Exhibition buildings at Chicago were coated by the use of nozzles.[1] Boiled linseed-oil, or red-lead paint applied by this method, would probably dry quickly; and these are the best for a priming coat for either the inside or outside of a ship.

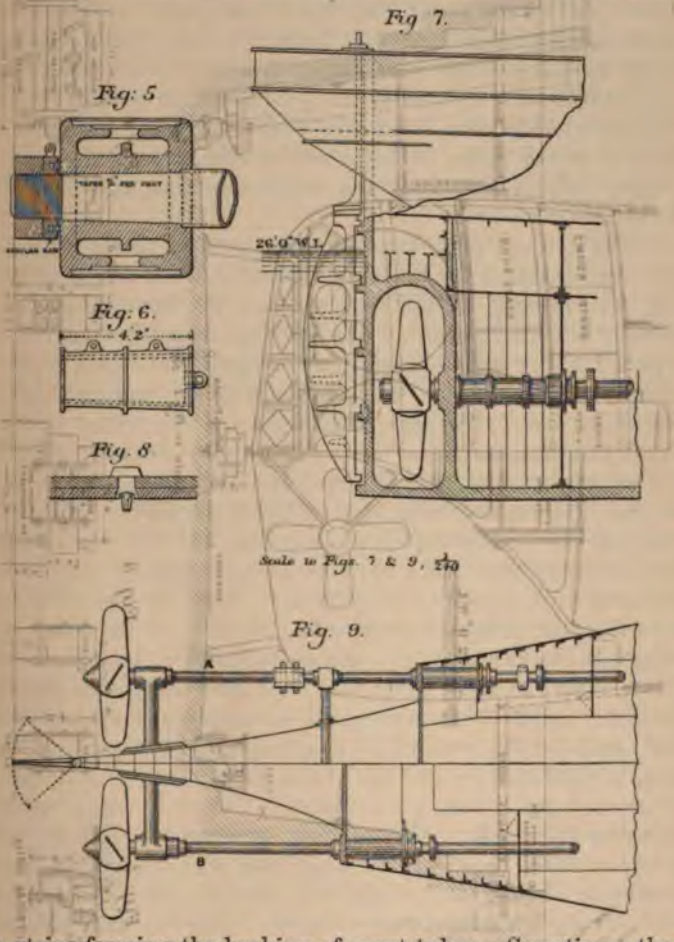
Rudder Work.—As most rudders are now fitted with loose pintles, and loose bushes in the braces on the rudder-post, the upkeep is simple. On docking a 4,000-ton steamer, the Author once found the rudder-frame broken in two places near the bottom. In hauling the rudder clear of its trunk at the ship's counter there was only 6 inches clearance, so that a rudder-pit would have saved anxiety. No crane being available, derricks had to be rigged and the rudder fleeted over to a barge, sent to the forge, and repaired. The bushes on the rudder-post were made good and proved, the ship floated and towed to the loading-berth, and the rudder shipped afloat. A coupling with carefully-fitted bolts is frequently fitted some distance below the counter, which further facilitates repairs; the latest form of frame has long projecting tails across the whole breadth of the single plate forming the rudder proper, on alternate sides, as shown by the dotted and full lines in *Fig. 7*.

Propeller Work.—In a propeller with loose blades, any found broken or seriously decayed can be easily replaced by new ones, as the weight is comparatively small, and the nuts on the studs holding them to the boss are readily unscrewed. When the boss appears to be amiss or does not fit well on the shaft, the nut is at once slackened back, and the boss is then struck with a ram or tup, conveniently hung by tackling. If a few blows will not start it the heat from a wood fire may be resorted to; and a steam-jet has been suggested for this purpose. But if the boss was originally well bored and fitted to its shaft it should be readily started or driven into position by hydraulic power, the nut being simply screwed up. The tup or battering-ram should be discarded as dangerous, and has split many bosses. An annular ram, about 6 inches long over all, for driving a boss home, could be placed between the boss and the nut, the latter being made sufficiently deep to avoid distorting the threads on the shaft, *Fig. 5*. For drawing a boss off a shaft the ram would be in rear of the nut,

[1] "The air-compressor used in the mechanical process of painting the Exhibition buildings at Chicago, is a rotary one, which, when driven by an electric motor, compresses air from 15 lbs. to 18 lbs. to the square inch. The air is then mixed with calcimine; and both are impelled, through a hose, upon the surface being painted or calcimined, from the nozzle in the hands of two men on the scaffolding."—*Engineering*, Feb. 3, 1893, vol. lv. p. 145.

Fig. 1.
STATE ROOMS
STATE ROOM
FUNNEL
HATCH
22' 0" W.L.
Scale to Fig 1, 3/8"
Fig. 4
Fig. 3
Fig. 2
ROWAN ELECTRICAL DRILL

which would be slackened back about $\frac{1}{2}$ inch, the power being transmitted by a pair of large bolts with shields or plates of ample strength. The boss must be taken off periodically in a single-screw steamer to allow an examination of the part of that propeller-shaft which works within the stern-tube, and to line up the lignum-



vitæ strips forming the bushing of most tubes. Sometimes these strips are cut to a template by revolving cutters, which give better results than can be obtained by fitting them by hand in place.

Some years ago the whole of the propeller-shaft between the boss and the inside of the stuffing-box gland in the tunnel was covered with brass liners, cast in two or more lengths, bored, heated, shrunk

on, and pinned. Gradually, however, the springing of the shaft produced a deep groove at the butt-joint, nicking the shaft in some cases ¾ inch deep all round. Subsequently, the central part of the shaft was left bare, and the ends bevelled, so as to avoid its "catching" against the neck-bush when drawn in towards the tunnel; but bushes are still shrunk on and pinned. As gun-metal is treacherous when hot, it is better to make an allowance by gauge, and draw the liner on cold, all in one piece, and by hydraulic power. The end of the liner may fit 2 inches or 3 inches into the boss; or the latter can be fitted to within ½ inch of the liner, in which space an india-rubber ring, ¾ inch thick, can be inserted, which will check the galvanic action and keep water out of the boss, *Fig. 5.*

For twin-screw propellers the same kind of annular hydraulic plant as described for the single-screw steamer would serve, not only for drawing off and forcing home the bosses, but also for drawing the bushes out of the brackets or A frames when they require relining with lignum-vitæ or white-metal, which could then be done in the factory. The shafts could then remain in place, if they have not to be removed for any other purpose. Ordinary screws are slow, and often become distorted at critical times.

Two methods of fitting propeller-shafting, shown in *Fig. 9*, indicate the needless work and expense avoided by being able to push out the bracket-bushes for refitting. In the one case, a box or sleeve coupling, which has been shrunk together with feathers, and cross-keys through it, would have to be taken adrift; and in the other, the tunnel-shafting would have to be disturbed by one length being removed, and the propeller-shaft length drawn in clear of the bracket. In dealing with interchangeable propellers, the Author prefers to use complete cone-gauges of sound cast-iron, male and female, instead of the ordinary plate-gauges, *Fig. 6.* Lugs or eyes cast on the top of the gauge representing the propeller, are for lifting purposes and trying it freely upon the propeller-shaft. By marking these cone-gauges, the true position of keyways can be set off, and much heavy work saved. The metal should be about 1 inch thick, with three circular ribs to assist in maintaining the shape truly circular. For the manipulation of twin-screw propellers and their shafts, the Author considers that hawse-pipes might be fitted with advantage in the counter or stern of the vessel, directly over the centre of the boss, *Fig. 1*, which would give a better lead for all necessary gear for dealing with the great weight, than the usual threading of chains over a ship's upper works. The shackles fitted by builders are usually only

suitable for dealing with single blades; but it is often convenient to take a propeller off bodily without disturbing the blades.

Stern-Frames.—A frequent accident to a single-screw steamship is the fracture of the stern-frame, either by grounding upon the heel, or by the continued striking of seas upon the rudder, reacting upon the bottom of the sweep near the inner post; and if a scarf occurs at that part and is not quite sound, rupture takes place, and in heavy weather probably the rudder is carried away with the after part of the frame, *Fig. 7.* The cutting out of a large stern-frame is a serious matter, as so much work is disturbed, including the clearing away of cement-work between the fine floor-plates forming the counter of the vessel, and drawing the shafting and stern-tube out of the way. The large rivets passing through both thicknesses of shell-plating and the body of the frame, are cut across the points with cross-cuts or diamond-points, and drifted out. As both sides of the ship are available, and several stages can be erected one over the other, this is the most simple part of the work. While the frame is at the forge being repaired and drilled to template, the vessel can generally be floated out if the dry-dock is needed for another vessel, or to save rent, and re-docked for finishing.

The stern-frames of two large first-class mail-steamers have recently been skilfully scarfed at the Thames Ironworks, in the centre of the lower part of the frame, and about half-way up the rudder-post. The scarfs were all worked out to template, no propeller work was disturbed, and both time and money were saved. Some later vessels have had the stern-frame scarfed when new. Many stern-frames are now made of mild cast-steel, and when fractured by an accident, are cut out bodily and replaced. The inner stern-post is frequently carried up and secured to a plated deck by angle-bar collars and a deep floor-plate, giving great strength, carrying the weight well, and avoiding straining at the counter.

The Author once fitted a solid bulkhead of $\frac{5}{8}$-inch iron plate, from the point of the foreside of the top or arch of an ordinary frame, to the deck above, of a 5,000-ton steamer. The bulkhead was stiffened on the one side with two horizontal angle-irons, 6 inches by 4 inches by $\frac{5}{8}$ inch, and on the other side with similar vertical angle-bars. All unsound rivets in the neighbourhood were cut out, the holes being rimered and carefully re-countersunk, and served with Lowmoor rivets; and the whole stern was braced together, and gave no more trouble, *Fig. 7.*

Bottom Repairs.—For detaching the plates from the bottom of a

ship when the rivets are of iron, the usual plan is to cut the rivet-heads off in the holds, or any other clear space, after the ceiling and cement have been removed; but in a steel ship with steel rivets, the Author's experience is in favour of drilling from the outside, about the depth of the countersinking, with drills of nearly the size of the rivets, which can then be punched or drifted out. This operation also breaks up the cement, and the clearance of the remainder is much simplified, *Fig. 8.* Most ordinary indentions in good iron, or mild steel, if heated to redness, will roll out flat; but with deep and abrupt impressions, although the plate may stand fairing, it stretches so much as to throw the holes out of truth, and a new plate must be fitted. All steel plates should be annealed after fairing, preferably by a wood fire; and when cold, all the countersinking of the holes should be cleaned out afresh, as sound riveting cannot be made in a hole covered with scale.

When bottom plates are damaged the frames and floors become more or less bent and buckled; and their resetting in place, or their cutting out, scarfing, renewal, or giving compensation, requires careful consideration. A hydraulic rail-bender would often straighten a frame or buckled edge of a plate better than the ordinary bars and screws, and hammers generally used at gentle heats.

A most interesting instance of damage with which the Author had to deal, was that of a loaded twin-screw steamer, with a flat-plate keel of two thicknesses of steel, grating over a sharp-pointed rock amidships. The principal indentation was under a bulkhead, which relieved itself by a sharp local buckle; and the vessel touched the rock with her keel again some 50 feet further aft, and scraped upon it from that point to the stern-post. For further examination and repairs, the ship had to be "hung" from amidships to the stern. The vessel's weight was carried by three rows of shores on each side, with solid timber blocking under both sets of engines. The vessel was 420 feet long between perpendiculars, and 47 feet beam, and its weight as dry-docked was 4,050 tons, of which 3,000 tons were hung clear of the middle-line blocks, by shipwrights driving wedges in unison under each of the shores, and long folding wedges at the solid blocking. The weight being duly taken, the middle-line keel-blocks were readily cleared away, resembling the "setting-up" of a vessel previous to a launch. Cement-work, to an average width of 8 feet, was cut out fore and aft from the commencement of the damaged portion. At the fine part of the vessel aft, where through rivets could not be served, $\frac{7}{8}$-inch turned and tapped rivets of Lowmoor iron were employed, screwed in to

make a good fit; and they have stood perfectly for the last five years. The repairs occupied fourteen days working continuously; nearly all the bottom plates, which were of mild steel, were replaced; and the ship did not move, nor was anything strained or thrown out of line.

Double-bottomed ships are particularly troublesome to repair. If the damaged area is large the bracket floors, &c., are rendered more accessible by taking off many of the plates; and in closing up it can be arranged to finish within a short distance of a manhole, either in a hold or in the machinery space. The disturbance rarely reaches as far as the tank-top. The Author has seen many instances of damage of this nature, but only once heard of serious disturbance of the inner bottom or tank-top; and in that case it evidently saved the ship. Tank-tops under the boilers are subjected to great wear and tear, owing to more or less heated salt-water washing about, laden with ashes, *Fig. 1.* Occasionally the boilers have been hung from the upper part of the vessel, and shored from the keelsons for repairs. With long double-ended boilers, it is sometimes practicable to remove one set of bearers at a time, replacing them as the work of replating and caulking is completed. There should be a space of 12 inches to 18 inches left between the boiler-bottom and tank-top for cleaning and repairs. For renewing boilers in either a man-of-war or a mail-steamer, which cannot pass through the funnel-hatch combing-space, it is best to cut the necessary opening through the ship's side. A single-ended boiler, averaging 15 feet in diameter and 12 feet long, and double-ended boilers, could be drilled round and taken out in halves, saving much disturbance of the upper works and decks.

Double Bulkheads.—When water leaks into a compartment of a steamer carrying breadstuffs, peas, or seed, their swelling causes great strain and distortion, often far exceeding the injury caused by the accident; and unless this happens near a port, the bulkheads will probably be wrecked in rotation, and the vessel lost. In vessels carrying such cargoes, the Author strongly recommends the fitting of at least two double bulkheads, with two distinct sets of plating between double frames, from 24 inches to 30 inches apart, one at the after end of No. 1 hold, and one just abaft the engine-room, as least interfering with the working of the ship. Vertical plates could be fitted in line with the centre and side keelsons, so as to bind the two bulkheads together, as well as to the decks. With deep lower holds, two extra flats should be "worked in," like the decks of a caisson; and the bulkheads could be flush next to the cargo holds, avoiding the chafe of gussets, deep stiffen

ing bars, and broken stowage; and they must be provided with manholes for examination and repairs. The space between the bulkheads, not being available for cargo, should be excluded from the measurement of the ship's tonnage. The space being so small, the workmanship could be readily proved by water up to the upper deck; and being fitted with steam-pumps, it could be used as a ballast-tank, a chamber to check rolling, or a screen against fire.

Stem- and Bow-Damage.—When a laden steamer has been damaged at the stem or the bow, the cutting away of the damaged parts can follow down stage by stage as the cargo is discharged, so that the time in dry-dock is often very short, especially where a vessel is easily tipped. To avoid a group of short lengths of frame, as many as possible should be taken out down to the sweep of the stem, and all scarfs well separated, reversed frames being treated similarly. If a stem is but slightly twisted it can be heated in place and set fair; but it is generally necessary to take the rivets out to the top to give freedom for the expansion. Where the damage does not extend far down it is sometimes convenient to cut a fresh scarf, keeping the points clear of the plate landing-edges.

Lifting-Appliances.—For a pair of dry-docks, a 50-ton (or upwards) steam jib-crane, travelling on a good broad track, capable of serving either dock, and lifting pieces of machinery into or out of craft in the wet-dock, or railway trucks, would be very useful. Rolling cranes, similar to those at the Sandon Dock, Liverpool, serving the ship at right angles, avoid fouling the rigging and stays. Floating cranes are too uncertain in keeping to time to be depended upon for serving dry-docks, throwing work into confusion, and causing extra expenses. Moreover, it is unsafe to bring a craft against the caisson of a dry-dock for dragging at great weights.

Hydraulic Hoist.—A direct hoist might be readily arranged in one wing of a dry-dock, and would prove a great convenience, *Fig. 1*, as no ordinary crane will reach under a ship's counter, heavy weights being first lowered into the dock-bottom by the ship's own tackle. Any piece could be readily transported to the lift platform by a trolley on a metal traverse across the dock-bottom, where, after being cramped, it could be promptly raised to the truck-level. A single ram of 12 inches diameter, worked at 750 lbs. pressure per square inch, with a good cross-head and a pair of metal slipper-guides, should work well.

Hydraulic Capstans.—Three capstans should serve a dry-dock, one at the head, and one at each side of the entrance; and their

maximum load of, say, 10 tons should be plainly stated in cast figures on the head.

Hydraulic Drilling.—Water under pressure, available at convenient distances along the dry-dock, could be charged for, either by meter, or per machine in use by the hour. The Berrier-Fontaine drill, driven by a three-cylinder engine made of phosphor-bronze, is in use in most, if not all, of the French Government shipyards. Sir W. G. Armstrong, Mitchell, & Co. carried out some intricate drilling for bolts for the armour of H.M.S. "Victoria," in confined spaces, by this plant, with a pressure of 750 lbs. per square inch. They were manufactured on the Tweddell system, and are advantageous for drilling holes of 1 inch and upwards. The machine can be either placed against the work direct, or clamped down at some distance on planks; and by employing a "Stow" flexible shaft, a large area can be served without shifting. By using a worm-wheel and bar with cutters, side-light holes and other boring operations can be readily performed.[1]

Steam from Shore.—If a steam-ship is to be in dry-dock more than twenty-four hours it will probably be desirable to submit the donkey-boiler to the annual Board of Trade survey, and not worth while to work one of the main boilers. Steam of the required pressure could be supplied from the shore, through a flexible metallic pipe, for all the deck machinery, and for the turning gear for the main engines, and in winter time for heating purposes. Care would be necessary in plugging deck-scuppers, &c., to avoid interference with painting the ship's top-sides and bottom.

Filtered Water.—This is generally available by meter, but is costly, leaving room for a fair sliding-scale of prices according to quantity.

Gas-Mains.—A 4-inch or 6-inch gas-main round the dry-dock, with well-placed branches, would be appreciated, not only for lighting, but also for heating and motive power. A gas-hammer, placed on timber in the dock-bottom, might do good work. Gas fires for heating rivets should also be available.

Electrical Apparatus.—Although a vessel may carry electrical generating plant, it may be preferable to take the current from the shore, not only for lighting during repairs outside or inside the vessel, but also as a source of power, and for driving various tools or winches. Messrs. Denny & Brothers, of Dumbarton, have laid a

[1] Minutes of Proceedings Inst. C.E., vol. lxxiii. p. 64

large cable 1½ inch diameter, capable of transmitting 30 E.HP. at 100 volts, with 1-inch branches, throughout their shipyard. The Rowan drilling machines, on the current being made, magnetically attach themselves with a force of 2,800 lbs. wherever required, dispensing with drilling-posts and angle-plates, *Fig.* 2. Various forms of stirrup-irons are used for hanging the machines conveniently for their work. One form of the Rowan drill will bore a hole within 1½ inch of a corner; and another serves for radial work, such as drilling holes for boiler-furnaces in position, and counter-sinking them. Messrs. R. Napier & Sons have used some of these drills on H.M.S. "Gibraltar," for drilling 20,000 holes, $\frac{13}{16}$ inch diameter, for the sheathing, and a similar number for the protective deck; and about 200 holes were enlarged to 2⅜ inches diameter, through 2½ inches thickness of metal, for heavy bolts. It is consequently very desirable to make such tools, and also the hydraulic system, available for repairs.

The Paper is accompanied by ten photographs and a tracing, from the latter of which the *Figs.* in the text have been prepared.

(*Paper No. 2835.*)

"Restoration of Fitzroy Suspension-Bridge, Rockhampton, Queensland."

By Alfred Barton Brady, M. Inst. C.E.

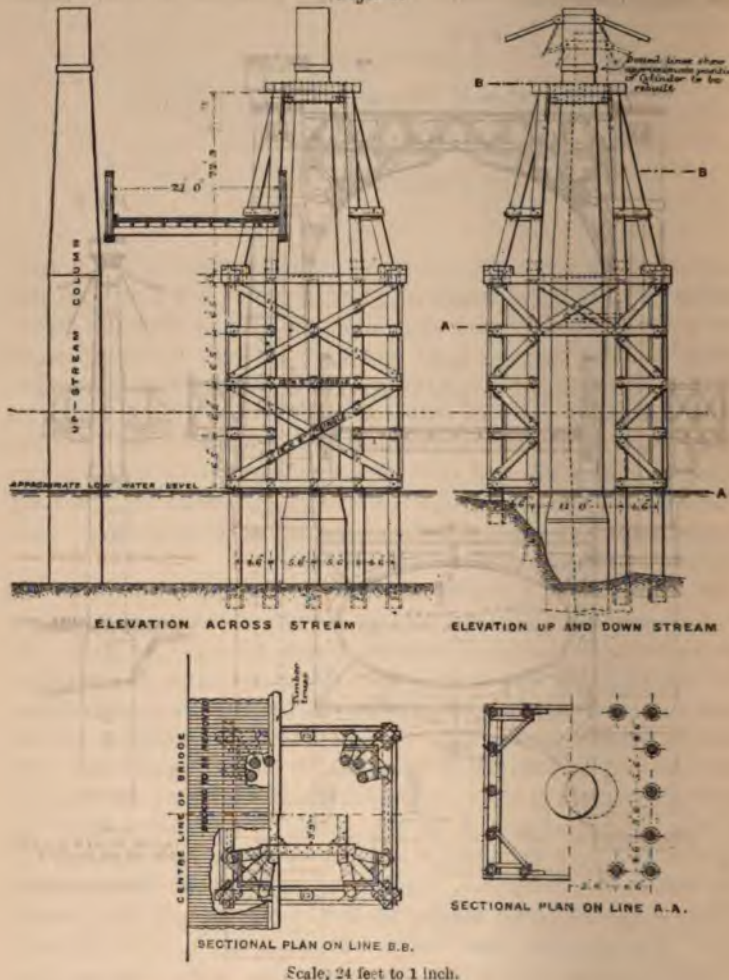
(*Abstract.*)

The bridge over the Fitzroy River at Rockhampton has a total length of 1,104 feet, divided into four spans of 232 feet each and two shore spans of 88 feet each. It was built in 1890 at a cost of £54,433. The roadway is 21 feet wide between the parapets, its surface being 24½ feet above the level of ordinary spring tides. The piers consist of pairs of cast-iron cylinders, 6 feet 6 inches in diameter, of 1-inch metal, spaced at 30 feet apart between centres, filled with concrete and connected by diagonal flat-bar bracing. The chains consist of wrought-iron links, pin-connected, and carry wrought-iron suspenders attached to H-bar cross-girders. The decking and hand-rail girders are of timber.

In April, 1890, a disastrous flood occurred, the water at the bridge attaining a depth of 50 feet (18 feet above ordinary spring tides), with a velocity of between 8 and 10 miles per hour. On the 9th of April the down-stream cylinder nearest the southern bank subsided, snapping the overhead cast-iron bracing, and canting over in a down-stream direction. A careful examination showed that the vertical subsidence amounted to 39 inches, and the horizontal movement at the base to 33 inches, the batter on the face of the cylinder being 1 in 24. Both of the cylinders at the injured pier were fractured, a number of suspenders buckled, and the timber truss crippled, besides minor injuries. The cause of failure appeared to lie mainly in the insufficiency of the foundation. The cylinder that failed had been sunk to a depth of 6 feet 9 inches below the river-bed, into shaly rock or clay slate, but by fracture and scour this depth had been reduced to about 1 foot 9 inches. The river-bed consists of Devonian slate and clay in alternate layers, dipping at an angle of 35° towards midstream. The Author concluded that the cylinder had been pitched on a ledge of slate which, by excessive pressure with

vibration, had become detached and slipped on an underlying band of clay saturated with water. The position in which the base of the cylinder was found bore out this explanation. The

Figs. 1.


UP-STREAM COLUMN
APPROXIMATE LOW WATER LEVEL
ELEVATION ACROSS STREAM
ELEVATION UP AND DOWN STREAM
CENTRE LINE OF BRIDGE
SECTIONAL PLAN ON LINE B.B.
SECTIONAL PLAN ON LINE A.A.

Scale, 24 feet to 1 inch.

TIMBER STAGING ROUND THE SUBSIDED CYLINDER.

total pressure at the base of the pier from dead load was calculated to be 5·6 tons per square foot and that from the maximum live load would be 3·93 tons per square foot.

A specification and drawings for the restoration of the bridge were at once prepared, and a contract was let in July, 1890, for the sum of £5,906 8*s.* 4*d.* This comprised the erection of a staging of ironbark timber round the subsided cylinder, *Figs. 1*, raising the suspension-chains with the bridge platform to their former

Fig. 3.

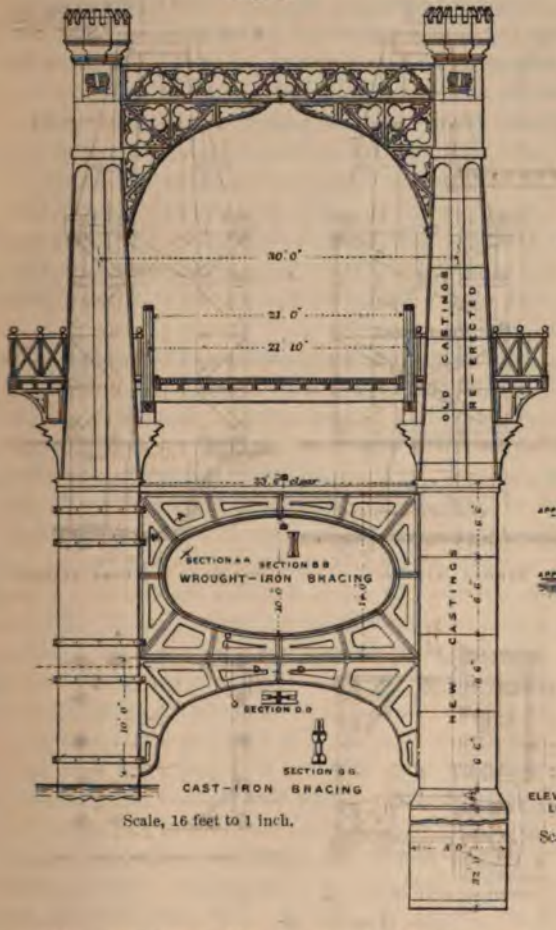
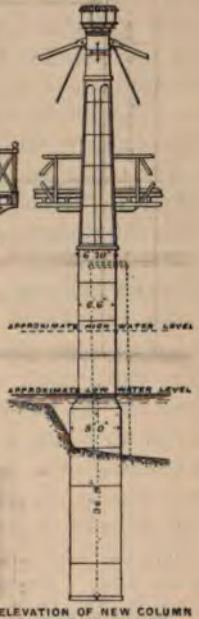


Fig. 2



position, removing the damaged cylinder and replacing it by a new and larger one, together with stronger wrought-iron bracing, replacing the chains on the summit of the new cylinder, placing concrete round seven other cylinders, and executing general repairs.

The staging, *Figs. 1*, consisted of fourteen ironbark piles, 18 inches in diameter, planted in holes jumped in the rock to a depth of 3 feet and packed with concrete. It measured 20 feet square and 45 feet in height, and was so spaced and braced as not to interfere with the removal of the old cylinder or the erection of the new one. On its completion a cast-iron collar in four segments was bolted round the turret, or upper portion, of the old cylinder, immediately below a projecting band, and under this collar were adjusted four hydraulic jacks, two of 60 tons and two of 50 tons, resting on the staging. The turret was then detached from the cylinder and raised by the jacks 40 inches, or 1 inch above its original position, to admit of the new cylinder being introduced. The load was distributed on the staging as evenly as possible by hardwood packings as the lifting proceeded. The rate of lifting was 1 inch per minute, the greatest load being estimated at 200 tons, and no straining of any part of the structure appeared to result from it. The lower part of the cylinder was guyed with steel-wire ropes in several directions.

The traffic over the bridge was suspended for one day only. The removal of the old cylinder occupied four days. It was broken up with the concrete contained in it and removed in pieces. Below low-water level it was lifted bodily and broken up as it emerged. The new cylinder was sunk, by loading it with rails and excavating inside, to a depth of 25 feet 6 inches in the river-bed, or 34 feet 9 inches below low-water level, *Fig. 2*, where it rested on very hard blue rock, which was cut out by divers to a depth of 21 inches and levelled. It was constructed in 6 feet lengths, the diameter being 8 feet up to low water, diminishing by a tapering length to 6 feet 6 inches above. The tapering length was cast after the sinking was completed, and made of the exact length to bring the top of the cylinder to the proper level. The 8-foot cylinders are $1\frac{1}{4}$ inch thick, and the smaller ones $1\frac{1}{8}$ inch. The heaviest casting weighed 3·84 tons. The cylinder was filled to a depth of 6 feet with concrete deposited under water. When this was set the water was pumped out, and the cylinder filled with concrete to the top. The new cylinder was united to the old up-stream cylinder by cast-iron spandrel bracing below and by wrought-iron bracing above high-water level, as shown in *Fig. 3*. The new bracing was attached to the new cylinder by bolts, and to the old one by set-screws. The cracked length of the up-stream cylinder was repaired by filling the opening with iron cement, and covering it by a wrought-iron cover-plate secured with countersunk screws, and also by banding the cylinder with wrought-iron bands.

It was found by a diver's examination that the rock had been broken and scoured away around seven of the other cylinders, leaving a pit 2 feet to 3 feet deep and 3 feet wide round the base of each. These cylinders were thus left with a hold of less than 2 feet in the rock. To strengthen this foundation they were surrounded up to low-water level with cement concrete, deposited in bags. Each bag contained 1 cubic yard, except where small spaces had to be filled up. When completed, the concrete formed a wall 5 feet in thickness round each cylinder, and amounted in all to 266 cubic yards. So far this protection appears to have been entirely successful. Originally the cylinders had been protected by dry stone ballast, about 1,500 cubic yards having been heaped round them, but after the flood of 1890 little of it remained. Two floods occurred during the progress of the works, the water rising respectively 6 feet and 8 feet above high-water level of spring tides, but no damage resulted to the staging or to any other part of the works.

The contractors were Messrs. Burns and Twigg of Rockhampton, who completed the work in a highly creditable manner on August 21st, 1891, the total cost being within the contract price. All the ironwork was manufactured in the colony by the contractors.

The Paper is accompanied by six photographs and two sheets of drawings, from the latter of which the *Figs.* in the text have been prepared.

(*Paper No. 2886.*)

"Otago Upper Harbour Improvement Works, New Zealand."

By GEORGE MORRISON BARR, M. Inst. C.E.

THE general features of Otago Harbour were given when the improvement of the entrance was described.[1] The present Paper deals with the works in the upper harbour, between Goat and Quarantine islands and Dunedin, *Fig. 1.* These islands are 7 miles from Dunedin wharf; and Goat Island is separated from the north-western mainland by a channel, 460 feet wide, only suitable for vessels of small draught. Quarantine Island is about 400 feet from Goat Island; and the channel between them has a depth of 73 feet, deepening to 114 feet at low water on the southern side of the islands. Through this opening the tide ebbs and flows with a maximum velocity of 3 knots an hour, maintaining these great depths, whilst a large deposit of alluvium has occurred at the adjacent parts. The eastern extremity of this island is 600 feet from a small peninsula jutting out from the mainland; and this channel is even worse for navigation than the other shore channel.

The main channel splits into two, 1½ mile above the islands, diverging to the south-east and north-west sides of the bay, up to which point the channel maintains an available low-water depth of 21 feet. The divided channels at once begin to shoal, and get worse as they approach Dunedin; so that between its beach and the opposite side of the harbour the low-water depths are only 1½ to 3 feet. The area of beaches and banks at low water is about 1,300 acres, or about one-fifth of the water-area at high tide. The contours between the fork of the channel and the head of the harbour are very irregular. In the main south-eastern channel, the 6-foot low-water contours extend to within ¼ mile of Dunedin wharf, with widths between them of 250 to 3,150 feet; but these depths, in the other half of the bay, only go to within 2¾ miles of the same point, owing evidently to a heavy landslip at a remote

[1] Minutes of Proceedings Inst. C.E., vol. cx. p. 304, and plate 2.

Fig 1
OTAGO UPPER HARBOUR.
To Christchurch
RAILWAY
KILGOURS PT
GOAT ISLAND
QUARANTINE ISLAND
CURLEW PT
BROAD BAY
YELLOW HEAD
GRASSY PT
RAINBOWS
MACANDREWS
BURKES PT
PORT CHALMERS
DUNEDIN
PROPOSED DOCK
GRANITE BRAES
LOGAN BAY
LONG OR SOUTH-EASTERN CHANNEL
Vertical Scale to Fig 2.
Scale to Fig 1 and Horizontal Scale to Fig 2.
Fig 2.
KILGOURS PT
BURKES
BAYNESBOURNE
DUNEDIN
ORIGINAL BED OF CHANNEL
DECEMBER 1875
1877
CLAY
MUD
SAND
DATUM LINE 40 FEET BELOW LOW WATER
LONGITUDINAL SECTION OF VICTORIA CHANNEL.
PACIFIC OCEAN

period. The 9- and 12-foot lines are more continuous in the north-western than in the south-eastern channel; though in the latter there is a larger area exceeding those depths than in the former. This applies with greater force to the 15-foot line, although at Grassy Point, there are some small pools with depths of from 20¼ to 25¾ feet.

Tides.—An analysis of the records of tides, kept for a number of years by Mr. A. Beverley, of Dunedin, enables the laws of the tides to be stated more accurately than in the previous Paper. At Dunedin, the period of flood is 5 hours 15 minutes, and of ebb 7 hours 10 minutes; but winds may affect their duration 30 minutes either way. In 1886–87, high water at Dunedin was 37 minutes later than at Port Chalmers; but the interval steadily decreased to 27 minutes in 1893. Before improvements in the upper and lower harbours were commenced, the mean range at Dunedin and Port Chalmers was 4 feet 9 inches; but by 1886–87 it had increased to 5 feet ½ inch at the latter place, and 5 feet at the former; and in 1893, the range at Dunedin was 5 feet 1 inch, and the range at the harbour entrance 1 inch greater. There is greater irregularity in the level of high water than in that of low water, the extremes being as 30 inches to 20 inches. These improvements in the range, and in the propagation of the flood, are clearly due to the operations on the bar, and in the channel of the upper harbour, the former giving the tide easier access to the estuary, and the latter giving a shorter and more regular channel for the flow of the water in the western channel. In November, December, January, May, June, and July, there are strong tides four or five days after each full and change, being greatest at the solstices. In the summer, the range is greater in the morning, and during winter in the evening. The highest tides are near perigee, and the lowest near apogee, whatever the moon's phase may be. When the moon is in apogee on the day before full or change, there is very little variation during the week preceding and the week following, except what is due to wind or barometrical pressure.

Early Schemes and Works.—In 1859, and also in 1868, the late Mr. J. T. Thomson, laid schemes of reclamation and channel improvement before the Provincial Government of Otago, resembling in principle the one since carried out, but differing from it in the heights of the training-walls, which he proposed should be low, half, three-quarters, and high-tide walls, according to position. In 1864 the late Mr. J. M. Balfour proposed another scheme, the distinguishing feature of which was a watertight wall

up to 2 feet above high water, extending from E on plan opposite Quarantine Island, up to opposite the centre of Dunedin, and thus placing Dunedin about the centre, instead of at the terminus of the tidal flow, as the flood tide would have gone up the north-west side of the wall, and turning round the end near Dunedin, would have come down the south-east side, terminating at E. Subsequent experience has shown that large quantities of sand would have been carried by the flood tide off the banks, much of which would have been deposited in the docks, about the wharves, and at the great bend of the channel near Dunedin.

Till 1874, when a Harbour Board was constituted, the Provincial Government only carried out works at small expense to enable the vessels which came up by the south-eastern channel to approach and lie at the wharves at Dunedin. In 1871, on the recommendation of the Author, some dredging was done in the north-western channel, with the view of utilizing its deep water as far as practicable with a moderate outlay. These operations, however, were prematurely stopped after about three months' work; and nothing further was done until the Harbour Board commenced the development of the Victoria Channel. The approach dredged to the wharves from the south-eastern channel was oblique to the run of the tide, so it had to be protected and trained by a timber wall on the northern side. The spoil from the dredger was delivered across it from the first cut, 42 feet in width, by an endless train of boards driven by the engine of the dredger; and the working expenses of dredging and delivery were $3\frac{1}{10}d.$ per cubic yard. This mode of getting rid of the material was designed by Mr. J. T. Thomson; and the Author in 1869 adopted a similar plant, 130 feet in length, but driven by an 8-HP. engine, instead of by the engines of the dredger, costing £890, exclusive of the barges upon which it was carried. The forward motion of the train of boards was 45 to 50 feet per minute; and it removed 22 cubic feet of spoil per minute, at a cost of 7*d.* per cubic yard for dredging and carriage, including allowance for depreciation of the discharging plant. It was used first for widening the approach channel, and subsequently, in 1870, in the north-western channel, where, notwithstanding a considerable exposure, this plant proved very suitable for the operations.

Works carried out by the Harbour Board from 1874 to 1888.—The earliest work carried out by Mr. D. L. Simpson, the first engineer to the Board, was the dredging of portions of the south-eastern channel, the approach to Dunedin wharves, and parts of a steamers' basin, to meet the more pressing requirements of the trade, at a

cost of £8,400. In 1875, after a minute survey of the upper harbour, he submitted a scheme for making a channel from Dunedin to Kilgours Point, 300 feet wide, and 24½ feet deep at high water, or 18 feet at low water, by dredging 4,907,954 cubic yards, and by half-tide training-walls, at an estimated cost of about £223,000, *Figs. 1* and 2. At the end of 1876 a contract was entered into for the formation of the proposed channel, only 70 feet in width, for £89,250; but it was cancelled after about one-seventh of the whole had been done; and from the 1st of October, 1878, the dredging was carried on departmentally. A cut right through, to 14 feet at low water, was accomplished by the end of May, 1882, though a considerable length through sand had to be re-dredged more than once. Along the first mile, when the cut was in clay with a layer of silt on the top, good progress was made; but through the sand-banks further down the channel, where portions were dry at low water, the progress was slow, for the work depended on the tide, and the very fine material was carried away from the buckets of the dredger by currents, much of it settling in places from which it had again to be removed by the dredger. Suction-dredging would have been the proper method of removing that material; but, on account of the large amount of plant on hand when the Author became engineer to the Board in 1882, it was not considered desirable to incur a further considerable expenditure. On the completion of the 14-foot cut, the channel was straightened in the neighbourhood of the cross-channel, and the whole length deepened to 16 feet at low water by the end of 1887, 1,994,074 cubic yards having been removed. The cost amounted to £116,524, or 1*s.* 2*d.* per cubic yard, consisting of dredging 9½*d.*, deposit (except by hopper dredger) 3*d.*, and towage 1½*d.* per cubic yard. This rate is exclusive of the outlay afterwards incurred in distributing the stuff over extensive reclamation areas.

The disposal of the spoil varied according to times and circumstances. Up till 1882, a large portion was dropped from punts behind the half-tide wall, and in some of the bays along the harbour; but as these were open to the full influence of the tide, except at Blanket Bay where a wall was constructed along part of its length, much of the deposit was probably carried away by currents. The portion which was not so disposed of, was delivered by cranes and derricks along the frontage of the Board's property, and latterly distributed by wagons running on rails.

The half-tide training-wall was not commenced simultaneously with the dredging, nor was it carried out steadily. In 1879, the part A B was undertaken to block off the side currents which

flowed between the sandbanks in that neighbourhood, *Fig. 1.* In 1880–81, the wall was extended southwards to C, causing the confined current to scour to a depth of 20 feet at low water about 2 miles from Dunedin, where the stiff clay on the western side prevented an extension of width. When the Author took charge, he recommended the continuance of the wall further southward, as its stoppage had induced the formation of a shoal close to its termination, by the meeting of the two flood-currents travelling by the different channels; and when this was carried out in 1883–84, the sand ceased to accumulate in the channel. In 1883–86, the half-tide wall was extended northwards to D. The construction of the wall has had a considerable effect upon the advance of the sand towards Dunedin. The wall was mostly carried on by day labour; and the cost of the stone in place amounted to from 1*s.* 10*d.* to 2*s.* 3*d.* per cubic yard, exclusive of allowance for plant. The northern part up to D was done by contract, at a cost of 3*s.* 3½*d.* per cubic yard; but as the stone was brought from Goat Island, the circumstances were less favourable than in the day-labour works. The cost of quarrying and filling into wagons 31,000 cubic yards of stone by contract near Dunedin, was 1*s.* 1½*d.* per cubic yard, and for 10,940 cubic yards of clay, 10*d.* At the end of 1887, the expenditure on these half-tide walls amounted to £21,167, and on the higher wall at Blanket Bay, £3,644.

In the five years 1883–87, the least depths at low water were increased from 12¼ to 16 feet; the greatest depths from 23½ to 26¾ feet; and the average depths from 15½ to 18½ feet; and the least width at the 13-foot low-water lines was increased from 40 to 86 feet. The extreme depth of 26¾ feet was due to scour, *Fig. 2.* In 1886–88, vessels drawing 19 feet 2 inches to 19 feet 8 inches used the channel without difficulty; but since then, the depths have been reduced by silting, occasionally shoaling at the worst points to 12½ feet before dredging was resorted to. The chief areas of deposit are opposite Pelichet Bay, in the neighbourhood of sand-banks 2 to 3 miles from Dunedin, and near the junction of the cross channel, *Fig. 1.* In the steamers' basin, in a swinging berth at the southern end of the channel, and in the proposed large dock, 1,021,822 cubic yards were dredged at a cost of £61,954. Some of the material in the first-named locality was a stiff yellow clay, which had to be taken out of the buckets by spade work. A considerable quantity of timber was found 10 to 12 feet below the bottom.

Wharves and Sheds.—By the end of 1888, 4,520 feet of wharves had been constructed in Dunedin by the Board; and about 100

feet of wharf, built by the Provincial Government in 1870, are still in use. Piles of ironbark were generally employed for the wharves; though the latest wharves, in the steamers' basin, were made of totara, possessing great durability. The latter wharves were built open, to avoid interfering with the currents in the basin; but all the others are filled in at the back. The beams and planking are of ironbark, bluegum, and kauri. The piles have been driven so as to give low-water depths of 14 to 20 feet. The cost of the wharves built since 1882, has averaged £92 9*s.* per 100 square feet filled in at the back, and £29 14*s.* open. Sheds for protecting merchandise in transit have been built along the wharves, of red pine framing, with galvanized roofs and sides, founded on piles and sills in made ground; and on the tongue wharf in the steamers' basin, they rest upon its planking. The cost of those constructed since 1882, has been £18 4*s.* per 100 square feet on reclaimed land, and £12 12*s.* on the wharf. The total expenditure by the Board upon wharves and sheds has been about £70,000.

Reclamation.—The Harbour Board was granted nearly 400 acres of ground in Dunedin, and along the western side of the channel; but as almost the whole of this was covered with water at high tide, it had to be reclaimed before it could afford a revenue. Up to the end of 1888, 100 acres had been reclaimed, part of this land, however, being only wide enough to form the seaward boundary of future work. Of this area, fully two-thirds had been raised by deposit of dredgings, the remainder having been formed by material brought partly from the ocean beach, and partly from street and other improvements in Dunedin. The completed portions have cost approximately £69,550, and the incomplete portions £31,700; and the rents received for 27 acres already leased amount to £7,770, of which about £7,650 is derived from the reclaimed land. As extended occupation proceeds, the increased revenue will furnish a large contribution towards the interest on the cost of works. The desirability of limiting the amount of reclamation has been kept in view; and no prejudicial effect appears to have been produced by the exclusion of a portion of tidal water.

Results.—The facilities afforded by these works for vessels of larger draught to approach Dunedin have enabled the merchants of that town to carry on a distributing trade to other parts of New Zealand. The benefits, however, have not quite fulfilled early expectations; but this has arisen chiefly by reason of the greatly increased draught of vessels in which a large amount of the trade with Great Britain is now carried on, for had the class of vessel remained as it was when these works were designed, the

whole of the export and import trade of the port would have centred at Dunedin. As it is, many of the old type of sailing vessels, and some of the steamers built to carry large cargoes on moderate draught, resort to the Dunedin wharves; but some of the steamers berth at Port Chalmers. Large quantities of goods are also carried by the steamers of the Union S.S. Company of New Zealand, to and from other ports in the colony, where the conditions are suitable for the largest class of steamers trading to the United Kingdom. The training works at the entrance to the harbour, previously described, have now (December 1894) developed a channel 30 feet deep at low water across the outer bar, so that whatever works may be necessary in the future will be in smooth and sheltered water.

The Paper is illustrated by a tracing, from which the *Figs.* in the text have been reduced.

APPENDIX.

Four dredgers and one Priestman grab have been in use on the works, capable of dredging from 30 to 500 cubic yards per hour, and ranging in cost from £900 to £43,900. A detailed comparison of the cost of the stationary and hopper dredgers shows that, when the latter has to make a double journey of 26 miles to discharge the spoil, the working expenses and depreciation are about equal with the two systems; but the advantage of using the stationary dredger for reclamation renders it the more serviceable.

There were four steamers for towing, comprising two stern-wheelers, one paddle-steamer, and a small screw launch, which, however, was only used when the other plant was insufficient. The best results were obtained by one of the stern-wheelers.

The material was carried from the dredgers partly in side-delivery punts, and partly in boxes resting on flat-decked punts, the boxes afterwards being emptied on the site in course of reclamation by various hoisting plant. The cost of the plant up to the end of 1888 was £119,330, exclusive of one-half of the cost of the hopper dredger and of plant used in the works at the harbour entrance; its value at that date was £63,767; and the depreciation, therefore, was £55,563.

The coal used was a superior bituminous kind, obtained from the west coast of Middle Island, and cost 33*s.* 10*d.* per ton in 1882, and 23*s.* 5*d.* in 1886. One yard of stuff dredged required from 4·2 to 5·06 lbs. of coal.

(*Paper No. 2887.*)

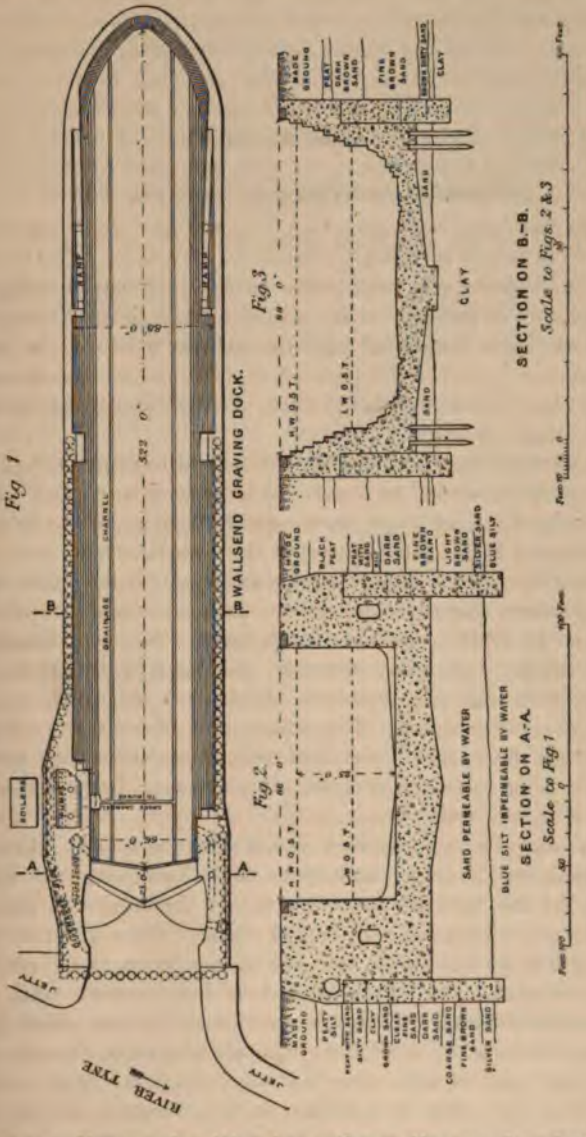
"Wallsend Graving-Dock on the Tyne."

By JOHN THOMPSON, jun., Assoc. M. Inst. C.E.

THE dock is situated on the north bank of the river Tyne, about 4 miles from its mouth, on the site of a small shallow tidal basin. The dock has a length of 522 feet on the floor and of 545 feet to the gates; a width at coping of 88 feet, and at the entrance of 66 feet; and the depth over the sill at high water spring-tides is 25 feet, *Figs. 1*, 2 and *3*.

Foundations.—For 330 feet from the river, the dock is built in the old river-bed, covered by a permeable layer of sand and silt to a depth of 70 feet from high water spring-tides at the entrance. A very slippery laminated clay, with thin bands of fine sand, underlies the silt, known locally as cement clay; below this there is a strong brown clay, upon which the walls at the upper part of the dock are founded. Cast-iron cylinders, 6 feet in diameter and 1 inch thick, were sunk through the sand and silt in 6-foot lengths, with elm piles between them, in a line with the walls, and filled with concrete, *Figs. 2* and *3*. They extend along 330 feet of the dock, and, with the cofferdam across the entrance, similarly constructed, they kept out the water from the enclosed area. Trenches were excavated at the upper end of the dock for the walls which were founded upon the clay, three rows of 12-inch by 12-inch pitch-pine piles being driven into the clay round the bow of the dock to the cylinders on each side. Two rows of pitch-pine piles were also driven in front of the cylinders; and the heads of the piles being left projecting above formation level, were built into the concrete wall, *Fig. 3*. Two vertical flanges, 11 inches apart and 1½ inch thick, project 5 inches from each side of the cylinders to receive the elm guide-piles; and the bottom ring in each cylinder has a cutting edge. The elm piles fit into the vertical flanges, and are bolted to them by 1¼-inch bolts, 18 inches apart; and they acted as guides for the cylinders on one side. As the strata dip towards

the river, the cylinders at the entrance of the dock are sunk to the greatest depth, decreasing in depth towards the bow, *Figs.* 2 and 3;



and they are dispensed with where the walls are founded upon the clay.

The material from inside the cylinders was excavated by three-ton travelling cranes with grabs, the cylinders being each weighted with 80 to 130 tons of cast-iron before the required depth was reached; and the top of each cylinder was left about 3 feet above low water. When the material was very hard, or when stones of large size were encountered, it was removed by hand, and one cylinder cut through a 14-inch oak log, at a depth of 30 feet.

Excavation.—Inside the dock, in addition to slopes formed at the back to relieve the pressure, the cylinders were stayed across the dock with 12-inch by 12-inch stays, until the floor and walls in front of them had been put in. The material between the walls was taken out in sections 30 feet to 40 feet wide. The excavation near the entrance was raised by a lift on to a staging, tipped into hoppers, and deposited at sea; whilst that in the middle and upper end of the dock was taken up an incline by a winding-engine and wagons.

Drainage.—The drainage during construction was effected by a line of 6-inch cast-iron pipes down the centre of the dock, under the floor, and wooden runners along the face of both rows of cylinders, which were connected to the 6-inch pipe by branch runners about 40 feet apart. The water from numerous springs was collected in runners; and relief pipes were put through the floor, and left open until the work was set. Water leaking in at the guide-piles of the cylinders was also led to the main drains, which discharged into a sump outside the line of the gates, consisting of a wrought-iron cylinder, 8 feet in diameter and 10 feet deep, sunk below formation level, and closed at the bottom with concrete. The water was pumped from this sump into the river by a 10-inch centrifugal pump, working intermittently. The drainage at the upper end of the dock was led into a sump, from which it was pumped by a 6-inch pump.

Concrete.—The concrete in the walls consists of $4\frac{1}{2}$ parts of broken stone, $2\frac{1}{2}$ of sand, and 1 part of Portland cement. The walls inside the entrance are $14\frac{1}{2}$ feet thick at the base, and are stepped back by the altars to a width of 5 feet at the coping. Concrete, 3 to 1, was put in for 2 feet round the filling culverts, and for 4 feet round the granite quoins and behind the sill stones. All the concrete was mixed by a machine. A proportion of 15 per cent. of clean stones for displacers was allowed; no stones were permitted to be nearer the face than $2\frac{1}{2}$ feet; and a space of 4 inches left round them was well packed with concrete. All the faces of the walls and culverts were shovel packed. The Portland cement concrete used for the floor consisted of $3\frac{2}{3}$ parts of copper slag,

broken to pass through a 2½-inch ring, 1⅓ part of sand, and 1 part of Portland cement, making a concrete of 12 cubic feet to the ton.

Cement Tests.—The Portland cement averaged 108 lbs. to the bushel, without being shaken down; and when passed through sieves with 120 meshes to the inch, it left a residue of less than 10 per cent. The briquettes, made of 1 part of cement to 3 parts of standard sand by weight, after seven days in water had to stand a tensile strain of 150 lbs. per square inch, and at the end of twenty-eight days 225 lbs. per square inch. The averages of the tests taken during the progress of the work are given below :—

Age of Briquette.	3 to 1 Tests.	Neat Cement Tests.
	Lbs. per Square Inch.	Lbs. per Square Inch.
Seven days	167	395
Twenty-eight days . . .	240	491
Eight weeks	284	498
Twelve „	300	527

Rudder-Well.—The rudder-well is elliptical in form, with a major axis of 16½ feet and a minor axis of 6 feet; its depth is 11¼ feet; it is coped with Heworth stone, covered by a teak decking. The concrete floor and walls are 2½ feet and 2 feet thick respectively. For excavating the permeable sand down to 13¾ feet below the floor-level, cast-iron piles were driven round the well down to the silt. Each pile had a bulb down one edge, which fitted into a socket down the other edge of the adjoining pile, with sufficient play to enable the piles to be driven. After completing the excavation, the enclosed space remained perfectly dry; centering and boarding were put in, and the concrete deposited between the cast-iron piles and the boarding.

Cofferdam.—The cofferdam, consisting of a row of cast-iron cylinders sunk into the silt to a maximum depth of 80 feet below high water, with elm guide-piles between them, was raised 4 feet above high water, and filled with concrete up to the apron, *Fig. 1.* The cofferdam was stayed with timber on the inside; and with the cylinders in the side walls it formed a cofferdam extending 330 feet on both sides of the dock, and proved most efficient and water-tight. A sluice in one of the cylinders enabled the gates to be tested before the removal of the dam. On

the admission of the water against the gates, the bolts in the cylinder-flanges and guide-piles were removed, and the rings lifted by a 30-ton barge crane, those under low water being slung by divers, and those immediately above the apron being blasted with gelatine dynamite, divers slinging the pieces which were lifted by a 3-ton steam-crane in a barge.

Gates.—The wrought-iron, double-plated gates are flat on the inner side and curved on the outer side, with a level clapping-sill, *Fig. 1.* They have greenheart heel- and mitre-posts, and clapping-pieces, bolted on to the iron-work. Rollers and roller-paths are provided; but the anchor-straps, pivots, and plates can take the whole weight of the gates. The gates can be floated out of position for repairs.

Quoins, Shoots, and Culverts.—The hollow quoins and sill-stones are of Aberdeen granite, the coping-stones of best Heworth stone, and the altars of granolith (two parts of crushed granite to one of cement) made in 5-foot lengths. There are three timber-shoots on each side of the dock, one being 20 feet wide, and two 7 feet wide; and they are faced with granolith placed *in situ*, 1 foot thick. The two filling culverts are 6 feet by 4 feet, with greenheart paddles worked by hand, and iron sluice-frames, *Figs. 1* and *2*.

Keel-blocks.—The cast-iron keel-blocks are in three pieces, the centre piece being wedge-shaped, with three wood blocks fixed on to the top. They are placed $3\frac{1}{2}$ feet apart, and stand 3 feet above the floor. The first twenty blocks from the sill are tied together and bolted to the floor, to prevent the inrush of water from the filling culverts displacing them.

Pumps.—The two main 36-inch centrifugal pumps have disks $5\frac{1}{2}$ feet in diameter with six blades, and together raise 50,000 gallons per minute at 170 revolutions. One engine drives each pump, with one cylinder, 24 inches in diameter and 18 inches stroke, at a working pressure of 100 lbs. per square inch. They are fitted with Meyer's expansion gear to adjust the cut-off and power of the engine to the lift of the water. Each engine can be coupled to either pump. One 10-inch centrifugal pump drains the dock. There are two marine boilers, with safety-valves set at 120 lbs. per square inch. The pump-well is entered by a short culvert, 6 feet by 5 feet, with iron gratings at the entrance. The well is 38 feet long by 6 feet by 6 feet, *Fig. 1.* The main cast-iron suction pipes, 3 feet in diameter, are built into the concrete. The cast-iron discharge pipe, $4\frac{1}{2}$ feet in diameter, is built into the concrete wall, and discharges into the river, *Figs. 1* and *2*.

Appliances.—The dock is provided with a portable 10-ton

hydraulic crane and a 5-ton steam travelling crane, and also one 5-ton and two 3-ton hydraulic capstans. The working pressure of 1,500 lbs. is obtained from the previously existing accumulator on the works.

Several 3,000-candle-power arc-lamps are placed round the dock; and cargo lamps, each containing six 16-candle-power incandescent lamps, can be placed wherever work is going on.

Two ramps, 4 feet wide, with oak treads, having an inclination of 1 in 3, lead to the floor of the dock; and eleven wrought-iron ladders down the face of the walls give access to the altars and the dock floor.

There are timber jetties at each side of the entrance, *Fig. 1*, having three rows of 13 inches by 13 inches pitch-pine piles, the front row having a batter of 1 in 9, one row of 12 inches by 12 inches piles, and a row of 9 inches by 9 inches sheeting piles; and the $1\frac{1}{2}$ to 1 slopes are pitched with slag.

The engineers for the work were Mr. Sheriton Holmes and Mr. John Thompson, Newcastle-on-Tyne, the Author being the resident engineer. Mr. John Best of Edinburgh was the contractor. The dock was opened on the 12th of January, 1895.

The Paper is illustrated by a tracing, from which the plan and sections in the text have been reduced, and by five photographs of the works when in progress.

(Paper No. 2892.)

"Portland Cement and Concrete."

By JOHN WATT SANDEMAN, M. Inst. C.E.

THE objects of this Paper are, first, with regard to cement, to summarize the most reliable data from the mass of information accumulated upon the subject, with a view to assist in arriving at a uniform system of tests by which the quality of cement would be raised; and second, with regard to concrete, to place on record the results of experience gained up to the present time, to offer a few practical hints upon its manufacture and manipulation, and to give a short summary of the information available in reference to the action upon it of sea-water.

PORTLAND CEMENT.

The excellence of cement depends not only on the due proportion of its constituents, but also upon the care and efficiency with which the various processes of its manufacture have been conducted. The Author contends that it is outside of the province of an engineer to supervise or interfere with the process of manufacture, and the tests for quality should be confined to cement as offered for sale. Besides mechanical tests, a chemical test has been proposed, but chemists are unable to pronounce an opinion upon the soundness, or cementitious value of a cement, as analysis does not reveal the degree of calcination upon which its strength is largely dependent, and does not definitely distinguish between the free lime and lime in combination with silica and alumina.

In confining attention to the mechanical tests applied to cement, reasons are given for proposing to eliminate some and to retain others better calculated to afford a reliable estimate of its value. The following are the chief properties to be ascertained by mechanical tests:—Fineness of grinding, weight, strength, freedom from risk of expansion, &c.

Fineness of Grinding.—This is a property of great importance, the test for which is simple, and should never be dispensed with. It consists of sifting a known quantity of the cement through a

sieve of fine wire-gauze, and ascertaining the relative proportion of the unpulverized particles to those which pass through the sieve. Finely-ground cement, by taking more sand than coarse cement, makes a proportionately stronger concrete. It also gives greater freedom from risk of expansion or blowing, should such be liable to occur from excess of free lime, as this would be in the condition of fine powder and would more readily become air-slaked. As regards the degree of fineness, Mr. John Grant's specification in 1885 required that the cement should be ground so that the residue on a sieve of 5,800 meshes to the square inch should not exceed 10 per cent. by weight. The Author's firm has for some years used large quantities of cement ground so fine that only 2 per cent. was retained by a sieve of 5,800 meshes per square inch, and about 10 per cent. by a sieve of 14,400 meshes per square inch. The advantage obtained by fine grinding has been found to be so great that the Author recommends that this degree of fineness should now be generally adopted. Another important reason for advocating a greater degree of fineness is that it will enable test briquettes to be made with 1 of cement to 5 of sand, thereby affording a better knowledge of the constructive value and trustworthiness of the cement.

From the point of view of watertightness, one volume of fine cement, having 10 per cent. residue on 14,400 meshes per square inch, will make watertight concrete with two volumes of sand of average size of grains, while one volume of ordinary cement, having 5 per cent. residue on 2,500 but 25 per cent. on 14,400 meshes per square inch, would not make watertight concrete with more than about $1\frac{1}{2}$ volume of sand; so that the capability of the fine cement for producing watertight mortar would be about 50 per cent. greater. Fine cement would also effect a considerable saving in cost of freight and transport, as the unpulverized particles in coarse cement (equivalent to so much sand) and varying between 10 per cent. and 50 per cent. or more of the total weight would proportionately increase the cost of its conveyance.

Weight.—The weight of cement without other tests is no guarantee of its quality, as its weight varies with its degree of fineness, and, owing to the greater density of the unpulverized particles, coarsely ground cement weighs the heaviest. The cement should therefore be sifted before weighing. To obtain a more accurate comparison of the relative weights of cements a specific-gravity test has been suggested; but as a gauge of the quality of cement this test is unreliable. The weight test has been abandoned by German authorities, and the Author considers

that its value as a test of the quality of cement is not commensurate with the time and labour involved.

Strength.—Cement may be tested for tensile, crushing, transverse breaking, and adhesive strength; but the test for tensile strength commends itself for simplicity, and is equivalent to the test for adhesive strength as shown by Mr. Grant.[1] It can be made with comparatively small expenditure of time and labour, and has proved a most reliable gauge of the cementitious value of cement when applied to briquettes of cement and sand, and when increase of strength with age is taken into account. Tests of neat cement are still in use, but should be abolished as of no value.

As regards the cement-and-sand test, Mr. Grant said—"If it (the cement) gives the required strength when mixed with sand after four weeks, it may be accepted without fear," and, "the test of tensile strength with three parts of sand to one part of cement after twenty-eight days is sufficient, and makes every other test of minor importance." The Author has found that, as a proof of good quality, it is an absolute necessity that besides possessing a certain strength, the briquettes should increase in strength from 7 days to 28 days, and that properly aerated cement in which the strength does not so increase is unsafe, and should be rejected. It has generally been found that greater strength of mortar is obtained with coarse than with fine sands; this is chiefly due to the fact that coarse sands, having greater scope for and generally greater variation in size of the grains, the ratio of their interstices is smaller. This is shown by Mr. C. Colson's experiments,[2] in which, out of seventeen samples of coarse sands the average ratio of the interstices was 33·8 per cent., while that of eight samples of fine sand was 41·8 per cent. Coarse sands, besides having fewer interstices, have also less superficial area of grains to be surrounded, which increases the surplus of cement left to separate them. For example, a sand having grains averaging twice the diameter of those of another would have only one-half the superficial area to be surrounded, and one having grains four times the diameter, would have, similarly, only one-fourth the superficial area. To secure uniformity of tests, a standard size of sand, obtained by sifting it through wire-gauze, should be used.

From the foregoing considerations it is recommended that tests should in all cases be made with 1 of cement to not less than 3 of sand, and, with cement of the degree of fineness proposed,

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[1] Minutes of Proceedings Inst. C.E., vol. xxxii. p. 326.
[2] *Ibid*, vol. lxiv. p. 149.

1 of cement to 4 or 5 of sand. With a good cement, of which not more than 10 per cent. is retained by a sieve of 14,400 meshes per square inch, there should be no difficulty in complying with the following test, viz., briquettes made of 1 measure of cement to 3 measures of dry sand, which has passed through a sieve of 400 and been retained on one of 900 meshes to the square inch, will be tested at 7 days, 14 days, 21 days, and 28 days after being made, each test-piece being kept dry for 24 hours and the remainder of the time in water. The briquettes at 7 days shall bear not less than 90 lbs. tensile stress per square inch, and the briquettes at 14 days, 21 days, and 28 days shall regularly increase in strength.

Freedom from Risk of Expansion.—The following has proved a useful and ready test to show if there be any tendency of cement to expand or if it is too hot for immediate use. "Thin pats of neat cement mortar, 4 inches in diameter, $\frac{1}{8}$ inch thick at the centre and as thin as possible at the edges, shall not show any sign of expanding or cracking during 28 days, 27 of which they have been kept under sea-water." To prevent risk of expansion of cement in concrete it is generally recommended that it should be kept under cover and spread out in bulk in bins upon a wooden floor for at least three weeks before being used, and turned over so as to allow any free lime to become air-slaked. For coarsely-ground cements, aeration in this manner may be a necessity, but for finely-ground cements, more particularly when such have been separated by a blower, or slightly steamed after grinding, aerating is, in the Author's experience, unnecessary.

The following are the properties of cement to which it is recommended that engineering tests should be confined. 1. Fineness of grinding. 2. Tensile strength. 3. Freedom from risk of expansion, &c.

Use of Slag in Cements.—As there are now several Portland cements manufactured partially from slag products, the properties of which have yet to be put to the proof, more particularly for marine works, it is recommended that for such materials chemical tests should be made to ascertain the quantity of sulphuric acid contained in the cement, and the effect upon it of exposure to sea-water.

Concrete.

In proportioning the constituents of concrete, the ratio of cement to sand, and of cement and sand to aggregates, may be varied greatly, and instances are frequently met with where

these ratios are so varied without regard to relative strength and economy of the concrete. But there is a simple method by which, with the same ratio of cement to other materials, maximum strength and economy in concrete are attained. It is clear that with similar aggregates the strength of concrete depends upon the strength of the mortar, and the strength of mortar upon the ratio of cement to sand, so that in concretes having the same ratio of cement, that with the smallest ratio of mortar to aggregates will afford the greatest ratio of cement to sand, and will therefore be the strongest. For example, concretes with the same ratio of cement may be made (and sometimes are made) with the other materials varying in the following proportions:— No. 1. 1 cement, 2 sand, 5 aggregates; No. 2. 1 cement, 3 sand, 4 aggregates; No. 3. 1 cement, 4 sand, 3 aggregates. Assuming the cost per ton of the sand and aggregates to be the same, the cost per cubic yard of the three concretes would be nearly the same; but as No. 2 would be two-thirds the strength of No. 1, and No. 3 half the strength of No. 1, their relative values should be estimated accordingly. The mode of determining the most economical ratios of materials for concrete is as follows:—

1st. The ratios of interstices of different aggregates are required, and these were ascertained by the Author to be as in the following Table[1]:—

—	Weight of Aggregates per Cubic Foot.	Ratio of Interstices.
	Lbs.	Per Cent.
Broken limestone, the greater part of which would be gauged by a 3-inch ring	95	50·9
Gravel, screened free from sand, varying in size between small pebbles and pieces gauged by a 2½-inch ring	111½	33·6
The above limestone and gravel well mixed in equal proportions	113½	33·6
Sandstone varying in size between pieces gauged by a 4-inch ring and pieces gauged by an 8-inch ring	74	50·0
Sandstone varying in size between sand and pieces gauged by a 4-inch ring	92	34·0
The two above sandstones mixed in equal proportions	91¼	36·0

[1] Minutes of Proceedings Inst. C.E., vol. liv. p. 260.

2nd. The volume of dry cement and sand necessary to produce one volume of mortar (ranging between 1 cement and 1 sand and 1 cement and 3 sand) was found by the Author to average about one-third more than the volume of the mortar when set.

3rd. An aggregate, therefore, with interstices of 35 per cent., and adding 10 per cent. to insure that each piece of stone or gravel is surrounded with mortar, would give 45 per cent. of mortar, to which one-third, or 15 per cent., is to be added to give the volume of the cement and sand, equal to 60 per cent. of the volume of the aggregate; this ratio will give the following volumes of materials as the most economical for ordinary concretes in which watertightness is not essential.

Cement.	Sand.	Gravel or Broken Stones varying in Size between the residue left by ¼-inch Sieve and that which passes through a 2-inch Sieve.	Ratio of Cement to other Materials.	Ratio of Sand to Gravel.
				Per cent.
1	1	3·33 say 3½	1 to 4½	28·5
1	1½	4·16 „ 4¼	1 „ 5¾	35·3
1	2	5·0	1 „ 7	40·0
1	2½	5·833 „ 6	1 „ 8½	42·8
1	3	6·66 „ 7	1 „ 10	45·0

Watertight Concrete.—For dry-docks, sea-piers, reservoirs-walls, &c., the absolute impermeability of concrete is a necessity; for works in sea-water, to prevent chemical action upon the cement, as will be shown later, and in reservoir work, &c., to prevent leakage, and in such concretes the mortar must bear a higher ratio to the aggregates than in the ordinary concretes, for the following reasons:—In making concrete there will always be great difficulty in insuring that the aggregates are properly mixed so as to range from large to small, and in depositing concrete there will always be the possible contingency that some of the larger aggregates may separate from the mass; in both cases the ratio of interstices would be locally increased, and to guard against such contingencies it is necessary to provide a greater ratio of mortar. Judging from experience, the volume of mortar to insure watertightness should not be less than 50 per cent. of aggregates having 35 per cent. of interstices; adding, therefore, one-third of the volume of the

mortar, to give the volume of cement and sand, these would equal 66⅔ per cent. of the volume of the aggregates, which should allow for all contingencies, and insure the stones or gravel being surrounded with mortar. Finally, to make certain that the mortar shall be watertight the ratio of sand must be limited to about 2 parts of sand to 1 of cement.

From the foregoing considerations as to the variation in the volume of the interstices of different sands, it is evident that the impermeability of a mortar will depend not only upon the ratio of cement to sand, but also upon the kind of sand used; for example, with 2 parts of sand having 27 per cent. of interstices, 1 part of fine cement will fill the same and leave a surplus of 46 per cent. to surround the grains and allow for contraction in setting; but with 2 parts of sand having 44 per cent. of interstices, 1 part of fine cement will leave a surplus of only 12 per cent. The Author has made watertight walls of concrete with 1 part of cement, having 10 per cent. residue on a sieve of 14,400 meshes per square inch, to 2 parts of sand having about 27 per cent. of interstices and 4½ parts of large and small gravel, which would have interstices of about 35 per cent. or less, and it should be possible with cement of the same fineness to insure watertightness with 2 parts of all ordinary sands.

From these limits of the ratio of cement to sand, and of mortar to aggregates, the proportions of materials for watertight concrete with fine cement[1] must be as follows:—

Cement having Residue of not more than 10 per cent. on Sieve of 14,400 Meshes per Square Inch.	Ordinary Sands.	Aggregates with not more than 35 per cent. Interstices.	Ratio of Cement to Sand and Aggregates.
1	1	3	1 to 4
1	1½	3¾	1 „ 5¼
1	2	4½	1 „ 6½

Cost.—The cost of concrete when in large masses may be reduced by the use of rubble displacers which should be spaced at least 12 inches apart. For the foregoing proportions the cost would

[1] With ordinary cement watertightness would not be attained with more than about 1½ part of sand to 1 part of cement.

be estimated in the following manner:—First, in ordinary concretes, 60 per cent. of dry cement and sand are required to 1 volume of aggregates, but as this provides 10 per cent. more mortar than is necessary to fill the interstices of the aggregates, the ratio of the latter to 1 volume of concrete must be diminished to 90 per cent. and the total volume of dry materials to 1 volume of concrete would be 60 per cent. cement and sand + 90 per cent. of aggregates = 1·5 volume, making their shrinkage = 33 per cent. Second, in watertight concretes, 66·6 per cent. of dry cement and sand are required to 1 volume of aggregates, producing 15 per cent. mortar in excess of interstices, making the ratio of aggregates 85 per cent. and the total volume of dry materials to 1 volume of concrete = 66·6 per cent. + 85 per cent. = 1·516 volume, and their shrinkage = 34 per cent.

The cost of the ordinary concrete having the ratio of 1 to 7 would be as follows:—

	£.	s.	d.
1 cubic yard of cement at 84 lbs. per cubic foot = 1·0125 ton at 31*s.* 6*d.*	= 1	11	11
2 cubic yards of sand at 90 lbs. per cubic foot = 1·627 ton at 2*s.* 6*d.*	= 0	4	1
5 cubic yards of gravel at 112 lbs. per cubic foot = 5·4 tons at 2*s.* 9*d.*	= 0	14	10
8 cubic yards of dry material—33 per cent. for shrinkage = 5·36 cubic yards of concrete, costing	£2	10	10

	£.	s.	d.
Cost of 1 cubic yard of concrete	= 0	9	6
Mixing and wheeling to site per cubic yard	= 0	2	6
Shuttering	= 0	1	0
Water and pipes	= 0	0	2
Superintendence and timekeeping, say 5 per cent. on total cost	= 0	0	8
Total cost per cubic yard	£0	13	10

Manipulation of Concrete.—From a study of the facts adduced in regard to the greater strength and economy attained by duly proportioning the components of concrete, the Author strongly deprecates the slovenly and unscientific practice of using in the manufacture of concrete unscreened gravel and sand, as, although in cases where such material is employed the approximate ratio of sand to gravel is sometimes supposed to be ascertained by sifting a few samples, yet this ratio varies

so widely, viz., between 19·5 per cent. and 113·6 per cent., according to the tests of Mr. Colson already referred to, that it would be quite impossible to obtain uniformity. Moreover, as the ratio of sand to gravel in the most economical concretes has been shown to range between 28½ per cent. and 45 per cent., it is clear that the varying natural ratios of sand to gravel would not make economical concrete, as, even assuming that the ratio of sand in any gravel were exactly according to requirements, it would be immediately altered by casting the material into wagons or barges. Again, by tipping them on to a heap, the sand and gravel always separate and assort themselves under the influence of gravity, and the Author has witnessed the practical impossibility of combining the two again in due proportions when shovelling them out of a heap. Where concrete is made from unscreened gravel there must of necessity be portions of it in which the interstices of the gravel are not filled, and others in which the mortar is in excess, and in consequence the strength of such concrete is very variable. It would also be quite impossible with unscreened materials to make watertight concrete, except by using an unnecessary excess of cement, entailing a proportionately increased cost.

The strength of concrete depends upon the strength of the mortar, and the strength of mortar upon the ratio of cement to sand, so that it is of vital importance that the cement and sand should first be thoroughly mixed together dry, in order that each grain may have its due share of cement. In hand-mixed concrete this cannot be accomplished without turning over the cement and sand completely at least three times. After this has been done they should be cast on to the aggregates, and it is then only necessary to turn over the whole once dry. Water should be added while the materials are being again turned over until the water is thoroughly incorporated throughout the mass. This system of first mixing the cement and sand considerably reduces the labour, as it only necessitates turning over the aggregates once dry, instead of two or three times, as is the general practice; and as the aggregates average more than twice the bulk and weight of the cement and sand, the saving of time and labour is considerable.

In hand-mixed concrete, the quantity of water necessary to render one mixing of the proper consistency having been noted, the same quantity of water should be used for each mixing, the uniform consistency of the concrete being of vital importance.

The thorough hydration of the cement is also of paramount importance; but as the quantity of water required will vary with the age and quality of the cement, the character of the sand and aggregates, and the state of the weather, the proper quantity to insure thorough hydration, without washing the cement out of the concrete or causing the aggregates to settle down in contact with each other, can only be determined by the observation of an engineer experienced in the manufacture of concrete. It may be stated as a guide that, when deposited *in sitú*, the concrete should be somewhat of the consistency of dough, and should always yield sufficiently to allow of a man treading it to sink into it to a depth of at least 6 inches. Workmen should always be employed to tread and shovel each mixing of concrete throughout, while it is being deposited, otherwise watertightness will not be attained. In order to ensure this, engineers should require contractors to provide men treading the concrete with waterproof boots. Concrete-mixing should not be allowed to proceed during very windy or wet weather, unless performed under efficient shelter, as a considerable percentage of the finest and most valuable part of the cement will be blown away, and during rain the cement and sand cannot be efficiently mixed.

The concrete should in all cases be deposited in such a manner as not to allow the aggregates to separate from the mortar under the influence of gravity. To lessen this risk the size of the largest aggregates should be limited to such as would pass through a sieve with meshes 2 inches square. Further to prevent the separation of aggregates, concrete should never be passed down a shoot, and, if tipped from a height, a layer of 2 to 3 feet in depth should first be deposited by lowering it in tubs. For large works regularity in mixing concrete may be attained by the use of a mechanical mixer, provided it be an efficient one, as there are so-called mixers which are worse than useless, by causing the separation of the aggregates from the mortars. The chief advantage of a good machine is the facility which it affords for making concrete with a uniform quantity of water and of uniform consistency, which cannot be easily attained by hand-mixing.

Action of Sea-water upon Concrete.—As regards the action of sea-water upon Portland-cement concrete, Mr. P. J. Messent has shown, by experiments undertaken in connection with a report upon the failure of the Aberdeen Dry-Dock in 1887, that if concrete be made porous or permeable in situations where sea-water can percolate through it continuously, it rapidly becomes disintegrated.

The disintegrating action has been erroneously attributed to the action of magnesia either in the cement or in sea-water, and to the presence of free lime in excess in the cement; but both magnesia and lime have been added to cement without causing disintegration. While doubtless defective cement would cause disintegration, yet it has been clearly shown by chemists that the disintegration of porous concrete in sea-water is due to the action of sulphuric and hydrochloric acids existing in small quantities in the sulphate and chloride of magnesium in sea-water. These acids readily leave the weaker base magnesium (which is deposited as a hydrate), and combining with a portion of the lime in the cement, for which they have greater affinity, expand and disintegrate the concrete. The chemical aspect of the question has been fully discussed by Dr. Michaelis,[1] who has also given valuable information as to substances which assist in preventing concrete from being acted upon by sea-water.

Professor Brazier, of Aberdeen University, has made experiments[2] upon the action of sea-water on concrete, of which the following is a summary:—indurated Portland-cement was exposed to the action of sea-water and to solutions of sulphate and chloride of magnesium, and in about three months' time it was found that in all cases nearly the whole of the magnesium was precipitated as hydrate, and that lime from the cement was dissolved, partly held in solution, and partly precipitated as sulphate and carbonate of lime.

It is stated by Mr. J. Pattinson, County Analyst for Northumberland, with reference to an analysis of disintegrated concrete:[3] "These results show that the chemical action between sea-water and cement had actually taken place, that is, that the lime of the cement precipitates (as hydrate) the magnesia of the magnesium chloride and sulphate contained in sea-water, with the consequent formation of calcium chloride and sulphate. If the cement or concrete is continually brought into contact throughout its substance with fresh portions of sea-water, there will be a continued deposition of hydrate of magnesia and probably sulphate of lime, and removal of lime, necessarily resulting in the disintegration and destruction of the concrete." Lastly, Mr. A. E. Carey has shown[4] that the addition of 5 per cent. of sulphuric acid to the water

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[1] Minutes of Proceedings Inst. C.E., vol. cvii. pp. 372, 375.
[2] *Ibid*, vol. cvii. pp. 78, 99.
[3] *Ibid*, vol. cvii. p. 76.
[4] *Ibid*, vol. cvii. p. 55.

with which the cement is gauged, reduces its strength in 7 days to 27 per cent. of that of neat cement.

The foregoing statements sufficiently prove the destructive action of sea-water when allowed to pass through concrete; but it has also been abundantly proved, by the durability of numerous sea-works in Portland-cement concrete, that there is nothing to fear from the action of sea-water when the concrete is thoroughly protected from it, by rendering it impervious to the passage of sea-water, which can be effected by making it of the proportions and in the manner described in this Paper.

(*Paper No. 2841.*)

"The Main Drainage and Sewage-Disposal of Edinburgh."

By WILLIAM FAIRLEY, Assoc. M. Inst. C.E.

THE City of Edinburgh occupies an area of about 6,000 acres, and has a population estimated at 261,000. Its site varies in level between 26 feet and 330 feet above Ordnance datum, and may be said to consist roughly of four valleys, into which all the drainage gravitates. These valleys form part of the catchment-areas of three streams: (1) The Water of Leith, a river with an average flow of about 2,000 cubic feet per minute; (2) The Craigentinny Burn, now a common sewer; and (3) The Pow Burn, with an average flow of about 200 cubic feet per minute. The rock substratum belongs to the calciferous sandstones of the lower carboniferous period, and over a large area crops up to within a few feet of the surface. On the northern side of the city it is overlaid by thick beds of sand, while patches of boulder clay occur over the whole area, most frequently in the western district. The average annual rainfall is 28·40 inches. A large number of the houses are completely fitted with modern sanitary appliances, and an abundant supply of water from the Pentland and Moorfoot Hills is distributed and laid on to all but a few of the oldest class of buildings. The consumption of water is at present at the rate of about 40 gallons per head per day.

Previously to the year 1870 all the main sewers were constructed of rubble masonry of various cross sections; in many cases, where the cutting was through rock, a mere facing of masonry being required. That part of the city known as the "New Town," laid out in the years 1767 to 1800 and 1802 to 1822, was provided with a system of main sewers, large enough in almost every case for a man to walk through them for inspection, the size being frequently 6 feet by 3 feet, with flat bottom, battered sides and arched roofs. In the parts of the city more recently sewered, fire-clay salt-glazed pipes are employed, jointed with neat Portland cement and rope yarn; or brick egg-shaped sewers. No general system of ventilation has as yet been introduced, but on all new

works ventilators have been placed at distances of 100 yards apart. During the year 1888 a beginning was made to carry out a system of ventilation for the main sewers in the central district; generally this has been accomplished by introducing ventilating-shafts with gratings in the centre of the roadways, and, in the vicinity of public parks, by forming outlets in the shrubberies, at some distance from the foot-walks. A difficulty will always present itself in districts which contain breweries and manufactories, discharging hot liquids directly into the sewers, owing to the emission of steam from the gratings on the roadways or streets, and consequent risk to horse traffic.

For the past few years the average expenditure in drainage work and new sewers has been about £11,000 per annum. In designing new sewers, the rule generally adopted has been to allow a discharging capacity equal to 42 gallons per diem per head of population in the drainage area, one-half of that quantity being assumed to pass off in eight hours, together with a rainfall of 2 inches in twenty-four hours. This rule has been adhered to in designing the greater portion of the recently constructed sewers, and gives a capacity sufficient for all ordinary requirements. Except in special cases no allowance is made for subsoil water.

The city is divided into three main drainage-districts (Plate 5). (1) The Water of Leith, or northern district; (2) The Craigentinny, or central district; and (3) The Powburn, or southern district, each area discharging by a separate outfall to the sea. In all these districts the sewage has been utilized by private enterprise for irrigating grass lands, the total area thus dealt with being about 360 acres.

On the Water of Leith outfall there is an irrigation farm, at the head of the intercepting sewer, on the lands of Roseburn, with an area of 33 acres. This farm was formerly of much larger dimensions, being at one time about 250 acres in extent, and almost entirely outside the city boundary; it has, however, been gradually curtailed, owing to the use of the land for building purposes. The Lochrin outfall-sewer passes in an open stream, through the portion at present under irrigation, the sewage being drawn off by a main carrier and distributed in leaders by gravitation, so as to flow evenly over the ground. Only a small portion of the entire volume of the sewage is now required. The subsoil is mainly a stiff clay, and no proper system of subsoil- or under-drainage has been adopted; the effluent water is caught by intercepting ditches and delivered direct into the Water of Leith. The whole area is

under natural grass, and yields between four and five crops each season, the average rental being between £20 and £30 per acre.

On the central or Craigentinny drainage-area there are two irrigation farms, both situated on the north-eastern outskirts of the city; viz., the Lochend and the Craigentinny meadows. Lochend farm has an area of 43 acres, of which 35 acres are commanded by main carriers led from the point at which the main outfall-sewer from the city debouches into an open stream. The sewage is pumped up on to the remaining 8 acres by an undershot water-wheel, 14 feet in diameter by 3 feet 6 inches broad, driven by the sewage flowing to the lower area, and it is then distributed by means of underground pipes and surface hydrants. The Craigentinny irrigation farm extends from the point where the stream leaves the Lochend farm, to the foreshore of the Firth of Forth, along which it spreads for a distance of about 1½ mile. This farm, which has an area of about 236 acres, may be taken as typical of the others. The greater portion of these meadows was laid out upwards of two hundred years ago, and a part under Italian grass and other crops about fifty years ago. The surface of the ground is undulating, with a general slope seawards, and a large portion of it was formerly waste land, on which only sea-grass and whins could be grown. The subsoil varies between a stiff boulder clay and light sands and gravels. There is a complete system of under-drainage, consisting of 2-inch and 3-inch agricultural tile-drains, laid 10 yards apart and 3 feet deep. The sewage is led from the regulating-sluices and settling-tank along the higher grounds by main carriers 5 feet by 2 feet, delivering into secondary carriers 2½ feet by 2 feet. From these carriers small leaders and turf drains, 12 inches by 6 inches, are cut so as to distribute the sewage as evenly as possible over the surface of the meadow. The effluent water from the surface and the under-drains is caught by ditches, to be again used in irrigating lower levels, or delivered by the outlets into the Firth of Forth. The secondary carriers divide the ground into plots, each of about ¾-acre in area. Four crops are usually taken off the land annually, and occasionally, in dry and favourable years, five or six. The ground was originally sown with a mixture of natural and aquatic grasses, the latter in small quantities, and it has not been broken up since, nor has it been cropped in any other way. The 50 acres under Italian grass are situated at a higher level than the main area of the farm, and are cropped in rotation with the arable land, the sewage being raised by a pump driven by a steam-engine at the farm buildings. Two or three men, with the occasional

use of a horse and cart, do all the labour required, regulating the sluices, repairing roads, and keeping the carriers clear. From the month of May until the end of October, the whole of the sewage, amounting to about 800 cubic feet per minute is utilized on the land, each group of plots being under water about twenty-four hours continuously once every three weeks. During the winter, irrigation work is only carried on during fresh open weather. The average rental received is about £36 per acre per annum. The dairymen, and others who take the crops, cut the grass themselves as they require it, the proprietor attending only to the regular supply of water to the land, and the repair of the roads.

Another sewage farm, the Craigmillar meadows, is situated outside the city boundary, on the Powburn or southern outfall. This farm has an area of about 48 acres, of which 32 acres were laid out about fifteen years ago, and the remainder about the year 1885. The subsoil is a stiff clay, and there is no system of under-drainage. The sewage is led on to the farm by an 18-inch pipe, and is distributed by two main leaders 3 feet wide by 2 feet 6 inches deep, the effluent water flowing into an intercepting drain to again join the outfall sewer. The plots are laid out so as to secure as far as possible a uniform flow over the land, which is constantly under grass, and is divided into ½-acre plots. The quantity of sewage usually delivered to the farm is about 140 cubic feet per minute. Each plot is flooded for about twenty-four hours once a fortnight. The usual yield of this farm is four crops per annum, but in dry years five crops may be secured. The average rental is £20 per acre per annum. One man, with the use, for the greater portion of the time, of a horse and cart, attends to all the ordinary work, viz., regulating the sluices, clearing ditches, and repairing roads.

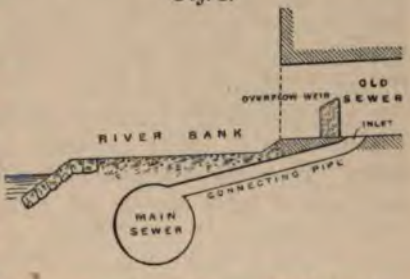
All these sewage farms are in the hands of private individuals, and they no doubt form a good investment, for after the meadows have been laid out, the expenses entailed in the maintenance and management are very small. The grass, which is annually put up in lots and sold by public auction, is readily bought by cowkeepers and dairy-farmers. It cannot be said that these farms play an important part in the purification of the sewage, the great bulk of the foul water merely runs over the surface of the ground and deposits a portion of its suspended matter, but where under-drainage has been provided, the effluent is fairly clear and pure. The presence of the meadows has a tendency to lower the value of land for building purposes in the immediate vicinity. Although no distinct nuisance may arise from them, their near neigh-

bourhood is not free from disagreeable odours, especially in damp warm weather. As at present conducted, these farms make no pretensions towards purifying the sewage, but as a profitable means of utilizing the sewage of a large city, by increasing the yield of poor land and thereby enhancing its agricultural market value, they are entitled to the favourable consideration of municipal authorities.[1] The northern drainage-district comprises the whole catchment-area of the Water of Leith and its tributary streams, so far as they are within the municipal boundary, together with a portion of the adjacent burgh of Leith. Within the city of Edinburgh there are 2,760 acres, with an estimated population of about 130,000, and an average sewage-discharge of 1,113 cubic feet per minute. Until the year 1863 the whole area drained into the river, which consequently became so polluted that frequent complaints were made of its unsanitary condition. A step towards improvement was effected by carrying the sewers across to the central part of the stream, where a considerable volume of water was continually flowing. The sewage was thus carried quickly out of the city, and was not left in pools and on the banks as formerly. As the city increased, further measures had to be taken to remedy the nuisance. In 1862 the requisite parliamentary powers were obtained to construct a main intercepting-sewer along the course of the river to the sea. This work was begun in 1864 and finished in 1867, the engineers being Messrs. D. & T. Stevenson. The intake is near the western boundary of the city, at a point where the Lochrin Burn, now almost wholly covered, joins the river. The sewer follows closely the windings of the Water of Leith, at a sufficient depth to intercept the main sewers discharging into it on each side, and terminates on the foreshore at a point called the "Black Rocks," in the Firth of Forth; the total length, comprising about 2,560 yards of egg-shaped brick sewer, is 5 miles 1 furlong 8·89 chains. The remainder of the outfall consists of cast-iron piping between 2 feet and 3 feet in diameter. For a considerable part of its course the sewer was in very wet and soft ground; and in the neighbourhood of blocks of high buildings the trench required to be carefully timbered. Along the shore at Leith the track was 20 feet from the quay-walls of the harbour, the sewer here being a 3-foot 6-inch iron pipe, which was continued to the outfall at the Black Rocks, 17 feet below high water of spring tides. As the point of discharge is near to deep

[1] The area under irrigation was, in the case of Lochend and Roseburn, reduced during the year 1894.

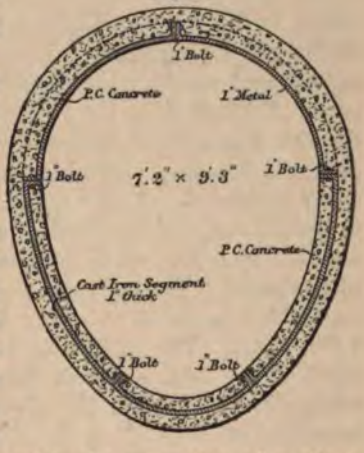
water, the natural sweep of the currents tends to carry away the sewage seawards. The connections between the main drains from the city were made as shown in *Fig. 1.* The iron-pipe sewer has a carrying-capacity equal to the calculated volume of sewage discharged from its drainage-area, together with a proportionate amount of flood-water, and all above that quantity passes over the weir into the river. At five points sluices were inserted to facilitate repairs when required. When this scheme was carried out, the estimated discharge was only 600 cubic feet per minute; but, since the completion of the work, the population on portions of the drainage-area has increased—in some cases fivefold—so that at the present time the quantity at the intake is 450 cubic feet per minute, and at the outfall 1,340 cubic feet per minute, ordinary dry-weather flow. The cost of the works was about £70,000, entailing a special drainage-rate of 2*s.* 6*d.* per pound on the rental within the area.

Fig. 1.



In 1888 a scheme was proposed to construct a large intercepting-sewer to relieve the Water of Leith pipe along the side of the river. An Act of Parliament was obtained, and the work has now been completed. The line of the new sewer follows the course of the 1864 pipe for a portion of its course, but diverges at Stockbridge (about midway) from the river bank, and follows a more direct line to the sea. The section of the culvert is circular throughout, with the exception of a short length at Leith Docks. The size varies between 4 feet diameter and 9 feet 3 inches by 7 feet 2 inches. The portion near the docks is in bad ground, and as the sewer would there be subject to internal pressure due to tidal action, it was constructed of a special section, *Fig.* 2, designed by the Author, formed of cast-iron seg-

Fig. 2.



ments lined and covered with cement concrete. This design was found to afford great facilities for rapid construction in bad ground.

The central or Craigentinny drainage-district comprises an area of 1,455 acres, with an estimated population of 107,000, the dry-weather sewage-discharge being about 800 cubic feet per minute. This district contains the densely populated part of the city known as the "Old Town," which covers the ridge between Holyrood Palace and the Castle, with the sloping ground on each side, and it is chiefly inhabited by the poorer classes. It contains also upwards of thirty breweries and numerous other manufactories. The main sewers on each side of this ridge consist for the most part of brick egg-shaped culverts, of sizes varying between 3 feet 6 inches by 5 feet 3 inches and 4 feet by 6 feet; these two lines of sewers form a junction within a few hundred yards of the municipal boundary, and subsequently flow in an open stream through the sewage farms of Lochend and Craigentinny to the Firth of Forth. Part of the main sewer, from the south side of this district, passes through the Queen's Park along the base of Arthur's Seat—a hill 822 feet in height.

As the greater portion of the drainage-area consists of paved streets and yards, with closely-built tenement houses, and as, owing to the steep inclination of the ground the storm-water is discharged during heavy rains with great rapidity, the authorities experienced considerable trouble from the flooding of the public park. Borings along the valley showed that it had formerly been the site of an ancient lake, and was made up of beds of clay, marl, peat and decaying vegetable matter, the ground subsiding as the decay proceeded. A new sewer was constructed in a line parallel to the old one, and consisted of an egg-shaped brick culvert 3 feet 4 inches by 5 feet, set in Portland-cement mortar. Piles of creosoted memel, 9 inches square and 5 feet to 30 feet long, shod with malleable-iron shoes weighing 25 lbs. each, were driven in pairs 8 feet apart. The piles were driven in a cutting of an average depth of 14 feet, a steam derrick with a 55-foot jib, set on a triangular framework, the pivoted centre and foot of each leg travelling on rails along the side of the track on a four-wheeled bogie, being used. After the piles had been driven to the required depth, the tops were cut square, and flat-bottomed rails weighing 70 lbs. per lineal yard were laid in 24-foot lengths, resting on the piles. The concrete foundation for the sewer was then laid, encasing the rails. This arrangement in 10-foot cutting cost £4 per lineal yard complete; the sewer itself, constructed in brickwork

with stone sills, cost 35*s.* per lineal yard. The sewage from the central area is, from the nature of the works &c. situated in it, extremely foul.

The Powburn, or southern, drainage-district comprises an area of 1,690 acres, with an estimated population of 17,000, the dry-weather sewage discharge being about 120 cubic feet per minute. About two-thirds of its area is covered by villas and suburban residences, the remaining portion not yet being built over, but building is proceeding rapidly. The whole district occupies a regular slope, ranging between 300 feet and 136 feet above Ordnance datum, and it formerly drained into an open stream running along its southern boundary. When the population and the volume of sewage was small, these drains passing down the slope discharged directly into this stream, which is called the Pow Burn, and joins the Braid Burn, a comparatively pure stream, at the eastern boundary of the city. Subsequently to 1880, this sewage was intercepted by the formation of a pipe-drain, and later on a brick culvert was constructed to a point beyond the city boundary. The Braid Burn, 3 miles from its junction with the Pow Burn, falls into the Firth of Forth near the town of Portobello, a watering-place much frequented by the residents of Edinburgh. Frequent complaints were made by the Portobello Corporation, of the pollution of the stream caused by the sewage from Edinburgh, and after litigation the referee recommended that an outfall sewer should be carried direct to the sea, with a discharge within a short distance of the Water of Leith outfall.

In 1884, a Bill was promoted in Parliament for powers to carry out the above scheme, and the work was begun in April, 1886, Mr. John Cooper being the engineer. The distance from the outfall at the sea to the junction with the existing city system is 4 miles 19 yards, and, in order to allow the work to be carried out expeditiously, the contract was let in two sections. This new outfall is distant 1,640 yards from that of the Water of Leith sewer, the sewage from the central or Craigentinny district being intercepted and discharged along with that of the Powburn district at a point 108 yards beyond the low-water mark. On the foreshore the sewer consists of cast-iron socket-pipes, 3 feet 6 inches in diameter, supported on piles of greenheart timber, 12 inches square, with two cross-bearers and one top-piece 12 inches by 6 inches. The substratum was a bed of clay of great depth, thickly interspersed with boulders, and great difficulty was experienced in the pile-driving. At the outlet an apron 8 feet by 5 feet was formed, consisting of greenheart sheet-piling 12 inches

by 6 inches with 3-inch planking. The Board of Trade required that a beacon should be erected at the seaward end of the outfall to mark the line of the pipes. At high-water mark, a concrete retaining-wall was built for a distance of 30 feet on each side of the sewer.

At the public road, where the brick sewer begins, an overflow chamber with a man-hole was formed of 18-inch brickwork in cement, with scabbled ashlar sills, the wall on the seaward side being of freestone ashlar in 16-inch courses. A wrought-iron penstock with 1½-inch gun-metal facings was erected against the mouth of the outlet pipe, the framework being 4 inches deep of 1-inch metal bolted to the ashlar work. From this chamber an overflow pipe, 24 inches diameter, was brought through the concrete wall to discharge on to the beach.

By an agreement with the proprietor of the Craigentinny Estate, provision had to be made to intercept the sewage discharged on the foreshore from the central outlet of the city, and for this purpose a cast-iron pipe, 2 feet 10 inches in diameter, was laid across the beach, joining the 3-foot 6-inch pipe at an angle of 45°. The intake, which is under the railway, has a catchpit or tumbling bay, consisting of a heavy concrete sill 2 feet thick, and side walls of 18-inch brickwork in cement, coped with ashlar work, and fitted with a malleable-iron grating. The seaward side is 18 inches higher than the other, so that in case of the pipe becoming choked the sewage would overflow on to the beach as formerly. At the main outlet the sewage is discharged into a strong current, the general set of which is north-east; any floating matter is therefore carried out to sea, clear of Portobello and the bathing beaches along the coast. The lower section of the contract included the work on the foreshore, together with 1 mile 1,000 yards of brick-sewer, terminating at a point on the public road at Duddingston, within 100 yards of the Braid Burn. The culvert consists of an egg-shaped sewer 5 feet 3 inches by 3 feet 6 inches and 5 feet by 3 feet 4 inches, built of 9-inch radiated composition-brick and cement, with stone sills. In the irrigated land the leaders for the sewage had to be kept running in troughs across the trench during operation, cast-iron pipes, supported clear of the made-up ground being put in after the trench was filled. In the arable land, the field under-drains were in many cases intersected, and intercepting-drains of 4-inch tiles were laid along the side of the trench, at an average depth of 4 feet, connection being made where necessary to the sewer manholes for discharge. By the Act of Parliament an agreement had been come to that the London

Road, which has a double line of tramways and also considerable vehicular traffic, should be tunnelled, and that no opening should be made in the roadway. The depth at this point was about 23 feet. Shafts 6 feet square were accordingly sunk on each side of the road, in private ground, and a mine was driven 7 feet by 8 feet, lined with sleepers 10 inches by 4 inches and 8 feet long. The sewer, after being built, was packed round with Portland-cement concrete in the ratio of 7 to 1. The cost complete for this work was £5 10*s.* per lineal yard.

A storm-overflow was constructed at Duddingston, the sewer at this point being 29 feet above the level of the Braid Burn. The upper section of the work was commenced at this point, drainage for the water from the cutting being obtained by means of the overflow. This section terminated in a junction with the Powburn intercepting-sewer, already mentioned, at a point 259 yards distant. From the point where the sewer leaves the public road at Duddingston, until it crosses the roadway at Craigmillar, a distance of 1,667 yards, the course is through the park of Duddingston House, the property of the Duke of Abercorn, in which it was stipulated that no manholes or ventilators should be employed. The cutting here was through extremely wet and soft ground, slips were frequent, and at one point where the excavation was 24 feet deep, 700 cubic yards slipped into the trench. The whole of the trench had to be close-timbered with 6½-inch by 2½-inch battens, and in some parts with 2-inch flooring-boards and straw-packing, the waling being 11 inches by 3 inches, with 6-inch square cross-pieces. Where there was any danger of the sills not being firmly bedded, a layer of cement concrete, in the ratio of 5 to 1, 4 feet wide and 15 inches thick, was laid as a foundation. The Braid Burn had to be crossed three times; this was readily accomplished by leading the stream through a trough, with framing formed of 11-inch by 3-inch planking, and 1½-inch lining, the ends being puddled with clay.

As already mentioned, the water of the Powburn sewer is used by the proprietor of the Craigmillar estate for irrigating meadow-land; an outlet had therefore to be formed in the new sewer to give off the required volume of sewage. The arrangement for drawing off the sewage consists of an outlet chamber and an 18-inch iron-pipe conduit, having a gradient of 1 in 500. The main sewer, at this point, drops 9 feet by means of reverse curves each having a radius of 14 feet. The siphon across the stream comprises two chambers, of 9-inch brickwork in cement with concrete-sills 12 inches thick, connected by an 18-inch iron pipe

laid 18 inches below the level of the conduit. The entire length of this outlet sewer is 4 miles 19 yards, with a difference of levels from the intake to the outfall of 163 feet. As the greater portion of the work was through private grounds, the contractor was allowed by the Corporation a width of 25 feet on each side of the sewer, the surface damages being paid by the city; but the contractor, Mr. John Best, of Leith, had to provide proper fences and to pay for any ground required outside the limit. In private grounds shafts 2 feet square, formed of 9-inch brickwork with stone covers 9 inches thick, were brought up to within 18 inches of the surface about every 150 yards.

The total cost of the work was about £40,000, exclusive of superintendence.

The Paper is accompanied by the map which is reproduced in Plate 5, and by tracings from which the *Figs.* in the text have been prepared.

(Paper No. 2795.)

(Abstract.)

"Widnes Sewerage."

By JOHN SMART SINCLAIR, Assoc. M. Inst. C.E.

WIDNES, situated on the north bank of the River Mersey, is a principal centre of the English chemical industry. Its important growth, which dates from about the year 1856, has been extremely rapid, as may be seen from the following Table:—

Year.	Population.	Number of Houses.	Rateable Value.
			£.
1861	6,893	1,150	30,000
1871	14,359	2,517	70,138
1881	24,918	4,994	131,651
1891	30,011	5,121	140,093

The town was formed into a Local Board district in 1865 and was incorporated in May, 1892. The area of the borough is 3,039 acres, including 256 acres of water in the foreshore of the Mersey. Of this area the sewerage system provides for 2,486 acres, the remaining 553 acres being agricultural land which it is considered need not be thus dealt with for many years. The site of Widnes inclines with a gentle slope towards the river from north to south, the average inclination being about 1 in 200, and it is drained naturally by Steward's brook, which forms the borough boundary on the western side, the Marsh brook, and Bower's brook, which traverses the centre of the southern portion of the town (Plate 5). The street levels vary between 164 feet above ordnance datum on the north-west boundary and 18·60 feet above datum near the river.

The greater part of the town is on the New Red Sandstone, forming the central elevated portion which inclines to the east and west respectively, the ground beyond this being stiff retentive boulder-clay. Water is used in large quantities by the numerous copper-smelting and chemical works in various manufacturing

operations. The quantity of water sold by meter to these works in the year 1893 was 630,026,000 gallons, *i.e.*, about 1,720,000 gallons per diem. The total volume pumped for manufacturing and domestic supply in the course of the same year was 853,894,000 gallons. The drainage from the factories is not allowed to be discharged into the public sewers. When the chemical works were first established, they were drained into the adjacent watercourses, which in process of time were enclosed in culverts by the manufacturers and by the railway companies, and thus served for a certain distance above their outlets as chemical sewers, discharging into the river.

Steward's brook, which is carried in culvert only where the railways cross it, receives the drainage from the waste heaps above Ditton Road. The deposits of chemical waste in Widnes, which are very extensive, occupying an area of about ½ square mile adjoining the river, are confined to the western side of the borough and are remote from dwelling-houses. The waste is packed in banks about 18 feet in height above the level of the soil. The chemical waste from the works on the east of the borough is deposited in the township of Cuerdley, and also covers a large area. The drainage from these heaps contains a considerable quantity of dissolved sulphur compounds, and great difficulty is experienced in preventing the infiltration of the yellow liquids derived from this source into the adjoining sewers.

The Marsh brook, which has an average gradient of 1 in 200, is also enclosed in a culvert, partly by a square timber flume through the river embankment, but for a distance of 450 yards adjoining the western outfall sewer in an open V-shaped channel, 12 feet wide at the surface of the ground, and 4 feet wide at the invert-level. This channel has an average depth of 12 feet, and the sides are lined with creosoted red-pine planks, 9 inches by 4 inches, laid on a bed of puddled clay 12 inches in thickness. The struts, which are 8 feet apart, are 9 inches by 6 inches, and are secured to pitch-pine walings 12 inches by 6 inches, 6 feet apart. Within this open culvert are two pitch-pine acid-troughs or carriers, each 9 inches by 9 inches internally, which rest on the struts. These troughs serve to keep the acid drainage (hydrochloric acid) separate from the other chemical liquors, and to discharge them direct into the river. If these liquids are allowed to combine, sulphuretted hydrogen is evolved and offensive odours result.

Bower's brook is carried, for a distance of 2,167 feet from the river, in culverts 7 feet 8 inches by 5 feet 9 inches and 6 feet by 4 feet 6 inches respectively, and has an average gradient of 1 in

300. It is a chemical sewer maintained and cleansed by the manufacturers. A quantity of domestic sewage is, however, delivered into it, pending the completion of the eastern outfall system, referred to subsequently.

The drainage from the copper-smelting works (employing the wet method) contains solutions of sulphate of soda and sulphate of iron, and these salts combine with the drainage from the chemical works, which contains a large quantity of chloride of calcium, to form a precipitate of sulphate of lime. This substance consolidates into a hard mass and has caused Bower's brook to silt up on several occasions, attaining in some places a depth of 3 feet. The deposit is formed in successive layers, decreasing the sectional area of the culvert to one-quarter of its normal size, and during heavy rainfall occasioning serious floods in the upper portions of the town. Much difficulty was experienced in dealing with this question, because neither the copper smelters nor the chemical manufacturers would be responsible for the nuisance. The effluent from each class of works was of itself harmless, the deposit being solely due to the mixture of two different kinds of manufacturing waste. A scheme proposed to remedy this evil, by the construction of a pipe-drain 18 inches in diameter from the copper-smelting works direct into the river, has for various reasons been delayed in execution.

The residential portion of the town (with the exception of the West Bank district, which is inhabited down to the water's edge) is situated about $\frac{3}{4}$ mile away from the river, and the space between the town and the river is occupied by the various works. The sewage is discharged by three separate outfalls, the central, the western and the eastern outfalls, as shown on the plan, Plate 5.

The central outfall sewer, which adjoins the viaduct of the London and North-Western Railway, is 3,434 yards in length, and has an average gradient of 1 in 650. It is constructed partly in brickwork, varying in section between 4 feet by 2 feet 8 inches and 3 feet by 2 feet, and partly in 18-inch pipes. The area drained by it is 150 acres. It is in Red Sandstone for a distance of 450 yards, the remaining portion being in stiff boulder-clay. It was the first sewer constructed in the town, being originally formed by Mr. John Hutchinson through his dock estate and extended from time to time by the Local Board.

Previously to the year 1880, the only portions of the town which were sewered were the parts known as West Bank and Waterloo Road districts, which drain into the central outfall sewer. The

central and the upper parts of the town drained into various ditches and into the chemical sewer (Bower's brook). In consequence of the rapid development of this part of the town and the want of adequate drainage, the Local Board resolved to proceed with an efficient system of main sewerage. After the preparation of several schemes by the former surveyor to the Board, it was decided to construct a sewer, now known as the western outfall sewer, from Marsh brook along Desoto Road, Ditton Road and Moor Lane to the Town Hall. Plans and estimates for this work were made, and, after an enquiry by the Local Government Board, the scheme was duly approved in July, 1880, and the work was begun in 1884. The sewer had a total length of 6,098 lineal yards, with gradients varying between 1 in 56 and 1 in 1000, and the cost of the work was £30,159. A length of 245 yards in the Marsh was executed in pitch-pine timber, the cross-section measuring 6 feet by 3 feet 3 inches, the remainder consisted of brick sewers and pipe drains. The sewer was carried out in sections, the fifth of which was designed by the Author, and this section, commenced in May, 1893, was completed in December of that year. The level of the outfall is 2·50 feet above ordnance datum, the mean level for four years of low water and neap tides being 0·92 foot above ordnance datum, while the mean level for the same period of high water of spring tides is as much as 14·93 feet above ordnance datum.

It was originally intended to keep the invert 8·58 feet above ordnance datum, but this proved to be impossible. The disadvantage of having the sewer tide-locked was, as far as the tendency to silt up was concerned, met by providing a sufficient number of penstocks and flushing-valves available for frequent use. The total drainage-area for this outfall is 1,616 statute acres. Provision was made for carrying off ½ inch of rainfall in twenty-four hours, exclusive of the flood water to be diverted into the watercourses. The number of houses within the drainage area in 1883 was 2,598 and the population was 13,688. It was estimated that this population might ultimately reach 50,000, and that the volume of sewage might amount to 267,523 cubic feet in eight hours, or in one hour to 33,440 cubic feet.

Owing to the nature of the ground to be excavated, and to the presence of quicksands, the outlet sewer for a distance of 245 yards was constructed of pitch-pine timber. Transverse sleepers, 9 inches by 6 inches, were laid 6 feet apart on a foundation of slag, 12 inches in thickness, broken to a 3-inch gauge. Upon these were placed longitudinal timbers, 12 inches square, notched into

the transverse sleepers and trenailed, the joints being scarfed. Above them were laid 6-inch by 4-inch transverse sleepers resting on longitudinal timbers, and on this substructure was erected a sectional framework, the uprights being dovetailed into the top and bottom timbers, with longitudinal angle-stays trenailed to them. The broken slag was brought up flush with the lower side of the planking; the sides, top and bottom of the sewer were sheeted with 7-inch by 3-inch deals, slip-tongued and grooved. The whole of the work was put together with trenails, no iron-work being used, owing to the corrosive action of the chemical liquors upon that metal. The space between the timber work and the close timbering of the trench was packed tight with clay puddle, and the whole of the timber was coated inside and outside with a mixture of sand, pitch and tar, applied hot. A timber flap-valve was secured to the framework of this sewer, and a hood was fixed above it to prevent stones from obstructing the working of the valve.

The foundation of the brick sewer for a distance of 900 lineal yards from the outfall was formed of iron slag, broken to pass through a 3-inch ring, laid to a depth of 12 inches and rammed to a solid mass, with fine slag ($\frac{3}{4}$-inch chippings) shaped to the contour of the invert. Great difficulty was experienced in timbering the trenches and in keeping the foundations clear of tide- and flood-water. Owing to percolation from the adjoining chemical sewer (Marsh brook), the invert level of which is about 5 feet above this sewer, Portland cement or hydraulic lime was not used for this portion of the work, the brickwork being laid in a compound of 3 parts of pitch, 1 part of tar, and 4 parts of sand, applied hot; a collar-joint of asphalt, $\frac{1}{2}$ inch in thickness, being formed between the rings of brickwork. The arch and sides were surrounded throughout with clay puddle to a thickness of 6 inches. Beyond a distance of 1,560 yards from the outfall, the bricks were laid in Halkin blue lias lime mortar, composed of 2 parts of sharp sand to 1 of lime, ground together in a mill.

Five penstocks and flushing-chambers are provided on this sewer; they are each 6 feet 2 inches in width and 7 feet in height, and are approached by side entrances. The penstocks are constructed of two thicknesses of 1-inch pitch-pine timber, grooved, slip-tongued and trenailed together, working in a cast-iron framework. They are manipulated from the surface of the road by screw-gearing, and suitable balance-weights are provided. Overflow-pipes from the flushing sides of the penstock and valve-chambers are connected with the outlet. These chambers are

furnished with special apparatus for working the valves, so designed as to form, in conjunction with the latter, flushing apparatus. Valves are also introduced to prevent the flow of sewer-gas past the ventilating-shafts, and these may in a similar way be used to impound the sewage for flushing purposes.

The shafts are 4 feet square internally, and vary in height between 20 feet and 40 feet. Above the line of chemical drainage, at 1,550 yards from the outlet, a water-trap is inserted in the sewer in order to prevent the chemical gases from passing above this point. There are also two flushing-tanks each of 1,480 gallons capacity, with automatic flushing-siphons. These tanks are supplied with water from the road-gullies, and have also a constant supply from the water-mains regulated to discharge once in every twenty-four hours. During ordinary rains the tanks discharge three times daily. On the part of the sewer just above high-water of spring tides is fixed a self-acting cast-iron flushing-gate which has a tipping-box with a counterweight on the same shaft. The apparatus is controlled by a jointed lever, attached to the flushing-gate. When the gate is shut, the water in the sewer rises, the tipping-box is filled with water from a feed-pipe, and is caused to overbalance, whereupon the lever rises and releases the pent-up sewage. Above this gate and attached to the same framework is a hinged air-flap, which also serves as an overflow if the tipping apparatus gets out of order.

The eastern outfall sewer at Moss Bank will have a total length of 2,332 lineal yards, but, as it has not yet been completed, a portion of the sewage which it is designed to convey still flows into Bower's brook, provision being made by a water-trap and ventilating shaft against ingress of gas from the brook to the sewer; which is also ventilated at the summit by an octagonal shaft, 3 feet in diameter and 48 feet in height above the surface of the road. The internal diameter of the sewer, at present discharging into the river, which is of pipes throughout, varies between 15 inches and 2 feet, and its average inclination is 1 in 250. The invert level at the outfall is 6·70 feet above ordnance datum. Two cast-iron hinged tide flap-valves, with lead facings, are placed in manholes, one 6 yards and the other 330 yards above the outlet into the river. Three automatic flushing-tanks, each of 1,480 gallons capacity, are provided in connection with this sewer, the upper part of which is furnished with two ventilating shafts 45 feet high and 3 feet square internally.

The tributary drains formed of 9-inch and 12-inch pipe are being proceeded with rapidly throughout the town; the total

length of drain-pipes laid during the three years ending December, 1893, being about 8 miles. These drains have an average gradient of 1 in 100.

When the Author inspected the western outfall sewer in 1890, he found it free from deposit, but the penstock and valve-gearing were destroyed, having rusted away through the chemical action of the sewer gases. He therefore recommended their removal, the cast-iron valves being retained to serve as air-flaps. The mortar composition employed in the construction of the lower part of this sewer, formed of pitch, tar and sand, had not proved satisfactory, the heat in the sewer causing the material to soften and to run out of the joints of the brickwork. The Author is of opinion, based on the experience of removing old sewers built in Portland cement and lias lime mortar which had for twenty years conveyed the drainage from chemical works, that under those conditions Portland cement is the most suitable material for the purpose.

The ventilation of the sewers by the shafts referred to, augmented by a considerable number of iron pipe ventilators, 9 inches and 4 inches in diameter, appears to be satisfactory. It is found, however, that the prevailing winds and the internal temperature of the sewers influence the upcast currents of sewer-air in the shafts, and observations are being made to ascertain whether any reliable data can be obtained in connection with this question.

The Paper is illustrated by a tracing showing details of the outfall sewers, and by a map of the drainage system, reproduced in Plate 5.

(*Paper No. 2794.*)

"Circular Wheel-Teeth."

By Archibald Sharp, B.Sc., Wh.Sc., Assoc. M. Inst. C.E.

Introductory.—In a pair of toothed wheels required to gear together with constant velocity-ratio, the form of the teeth of one wheel may be chosen at pleasure; the form of the teeth of the other can then be determined so that the required condition is satisfied. The tooth-outlines of the two wheels will, in general, be curves of different characters. It is of course convenient and desirable that the tooth-outlines of both wheels should be regular curves of the same character. The only curves satisfying this condition are those of the "trochoid" family and their parallel curves, including the epicycloid, hypocycloid and involute. Unfortunately the mechanical difficulties of forming these curves accurately are great, and it is often desirable to replace them by simpler curves approximating to them as closely as possible.

Since only a small arc is used to form a tooth-outline, the exact curve may be approximated to by a circular arc. Professor Willis'[1] method of drawing tooth-outlines consisted in replacing the exact curve by the circle of curvature at a certain point. The tooth form in some cases is such that there is, during contact of a pair of teeth, a considerable variation of the velocity-ratio. Professor Unwin's method[2] consists in replacing the exact curve by a circular arc which touches it at one point and cuts it at another; this gives a more satisfactory tooth form than Professor Willis' method. Mr. Grant replaces the exact curve by the circular arc which coincides with it at the pitch line, the addendum line, or the root line, and at a point midway. "The circle that passes through these three points is assumed to be as accurately approximate to the true curve as any possible circular arc can be." His three-point odontograph[3] is a record of the radii of the circular arcs and of the

[1] Minutes of Proceedings Inst. C.E., vol. ii. p. 89.
[2] "Elements of Machine Design." W. C. Unwin.
[3] "Odontics; or, The Theory and Practice of the Teeth of Gears." Grant.

distances of their centres from the pitch line, for teeth of a given pitch; the values for other pitches being easily formed by simple multiplication. The diameter of the rolling circle chosen is half that of the pitch circle of a twelve-toothed wheel. In the case of "cycloidal" teeth, since the radius of curvature of the epicycloid or the hypocycloid at the pitch line is zero, and increases rapidly as the curve leaves the pitch line, no circular arc can be said to give a good approximation to the portion of the curve near the pitch line. The Author has already described[1] a method of drawing circular teeth, which would give to a pair of wheels a very small variation of their angular velocity-ratio. In the present Paper the same problem is more generally investigated.

Fundamental Equation.—If A and B, *Fig. 1*,[2] be the centres of the two wheels the teeth of which are circular arcs having the centres M and N respectively, while a pair of teeth are in contact

Fig. 1.

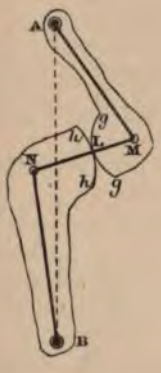
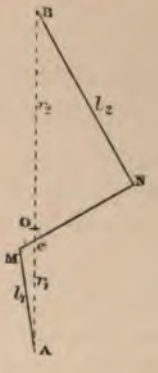


Fig. 2.



the angular velocity-ratio of the wheels will be the same as that of the links A M and B N connected by the link M N. Let r_1 and r_2, *Fig. 2*, be the radii of the pitch-circles, O the pitch-point, l_1 and l_2 the lengths of the links A M and B N respectively, and h the length of the connecting link M N. In any position of the four-link chain A B M N, let M N cut A B in the point e. Let M $e = x$, and O $e = y$. Expressing the cosine of the angle B e N in terms of the three sides of the triangle B e N, and

[1] Minutes of Proceedings Inst. C.E., vol. cxiii. pp. 241–260.

[2] *Fig. 1* is taken from the Paper referred to, Minutes of Proceedings Inst. C.E., vol. cxiii. p. 241.

the cosine of the angle A e M in terms of the sides of the triangle A e M,

$$\frac{(r_1 - y)^2 + x^2 - l_1^2}{2(r_1 - y)x} = \frac{(r_2 + y)^2 + (h - x)^2 - l_2^2}{2(r_2 + y)(h - x)},$$

that is

$$\begin{aligned}&(r_1^2 - 2r_1 y + y^2 + x^2 - l_1^2)(r_2 h - r_2 x + h y - x y)\\ &= (r_2^2 + 2r_2 y + y^2 + h^2 - 2h x + x^2 - l_2^2)(r_1 x - x y)\end{aligned} \quad . \quad (1)$$

When M N is in a position corresponding to contact of a pair of wheel-teeth in which the velocity-ratio is to be as nearly constant as possible, y must be small compared with the other quantities involved in equation (1); y^2 and y^3 may therefore be neglected, and (1) may then be written

$$\begin{aligned}&(r_1 + r_2)x^3 - h(2r_1 + r_2)x^2\\ &+ \{r_1(r_2^2 - l_2^2 + h^2) + r_2(r_1^2 - l_1^2)\}x - r_2 h(r_1^2 - l_1^2)\\ &= y\{-hx^2 - (r_1^2 - l_1^2 - h^2 - r_2^2 + l_2^2)x + h(r_1^2 - l_1^2 - 2r_1 r_2)\}.\end{aligned} \quad (2)$$

The angular velocity-ratio of the two wheels at the instant is equal to $\frac{B e}{A e}$. When this ratio is exactly equal to $\frac{r_2}{r_1}$, M N cuts A B at O, y is zero, and the corresponding value of x will be given by the equation

$$\begin{aligned}&(r_1 + r_2)x^3 - h(2r_1 + r_2)x^2\\ &+ \{r_1(r_2^2 - l_2^2 + h^2) + r_2(r_1^2 - l_1^2)\}x - r_2 h(r_1^2 - l_1^2) = 0.\end{aligned} \quad (3)$$

Simplified Equation.—Another method of obtaining an equation similar to (2) is the following. The link M N being fixed, and the curves described by the point O of the bar A B drawn, the equation to this curve may be regarded as equivalent to equation (2).

Taking M as origin, and M N as axis of X, let x, y be the co-ordinates of O, and θ the angle of inclination of A B to M N.

The co-ordinates of A and B are—

$$\begin{aligned}&x - r_1 \cos\theta,\ y - r_1 \sin\theta,\\ &x + r_2 \cos\theta,\ y_2 + r_2 \sin\theta,\end{aligned}$$

respectively. Therefore

$$(x - r_1 \cos\theta)^2 + (y - r_1 \sin\theta)^2 = l_1^2 \quad . \quad . \quad (4)$$

$$(x + r_2 \cos\theta - h)^2 + (y + r_2 \sin\theta)^2 = l_2^2 \quad . \quad (5)$$

Also

$$\sin^2\theta + \cos^2\theta = 1 \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

The portion of the curve lying near the axis of X only corresponds to actual contact of a pair of wheel-teeth, y is therefore small and y^2 and y^3 may be neglected. Eliminating $\sin\theta$ and $\cos\theta$ from (4), (5), and (6) (see Appendix I),

$$(2hr_1r_2y)^2 = \left[\begin{array}{c}(r_1+r_2)x^3 - h(2r_1+r_2)x^2 \\ +\{r_1(r_2^2-l_2^2+h^2)+r_2(r_1^2-l_1^2\}x \\ -r_2h(r_1^2-l_1^2) \quad . \quad .\end{array}\right]^2 \quad (7)$$

an equation representing two cubics symmetrically situated with regard to M N. One of the cubic curves is that described by O in the neighbourhood of M N when the links A M and B N are on the opposite sides of the centre-line to that shown in *Fig.* 2, and consequently does not correspond with contact of the same pair of wheel-teeth as the first cubic. The square roots may therefore be taken of both sides of (7), which may then be written

$$\left.\begin{array}{c}\pm 2r_1r_2hy = (r_1+r_2)x^3 - h(2r_1+r_2)x^2 \\ +\{r_1(r_2^2-l_2^2+h^2)+r_2(r_1^2-l_1^2)\}x - r_2h(r_1^2-l_1^2)\end{array}\right\} \quad (8)$$

If the negative sign be given to the term containing y, equation (8) will represent very approximately the portion of the curve described by O when the mechanism is near the position shown in *Fig.* 2.

The co-ordinates x, y, in (8) are different from those in (2). In *Fig.* 2 let O f be drawn from O perpendicular to M N; then x and y in (8) are respectively equal to M f and O f. The greatest value of O e corresponding to contact of a pair of well-designed teeth will, however, be so small that no important error will be introduced by writing O f for O e, and M f for M e. The velocity-ratio of the two wheels in any position will then be $\frac{r_2+y}{r_1-y}$, using the co-ordinates of (8). Equations (2) and (8) are identical in form, except in the coefficients of y. Equation (8), being the simpler, will be used in this investigation. The error introduced by using the simpler equation (8), instead of the more complex but more exact equation (2), is discussed on p. 272.

Determination of l_1, l_2, *and* h.—In order that the variation of the velocity-ratio of the wheels, during contact of a pair of teeth, may be as small as possible, it seems a fair assumption that the three positions of the crank A M, in which the actual velocity-ratio is exactly equal to r_2/r_1, shall be at equal angular intervals. It will be shown later, p. 12, that the assumption is justified. That the three roots of (3) should be of the form $p-q$, p, and $p+q$,

approximately expresses this condition. The equation having these roots is

$$(x-p)(x-p+q)(x-p-q)=0,$$

or
$$x^3-3px^2+(3p^2-q^2)x-(p^3-q^2p)=0 \quad . \quad (9)$$

In order that (3) and (9) may have the same roots, the coefficients of like powers of x must be equal. Therefore

$$3p(r_1+r_2)=h(2r_1+r_2) \quad . \quad . \quad . \quad (10)$$

$$(3p^2-q^2)(r_1+r_2)=r_1(r_2^2-l_2^2+h^2)+r_2(r_1^2-l_1^2) \quad . \quad (11)$$

and
$$(p^3-q^2p)(r_1+r_2)=hr_2(r_1^2-l_1^2) \quad . \quad . \quad (12)$$

From (10), (11) and (12) are obtained, (See Appendix II)—

$$h=\frac{3p(r_1+r_2)}{(2r_1+r_2)}, \quad . \quad . \quad . \quad . \quad . \quad (13)$$

$$l_1^2=r_1^2-\frac{(p^2-q^2)(2r_1+r_2)}{3r_2}, \quad . \quad . \quad (14)$$

and
$$l_2^2=r_2^2-\frac{(r_1+2r_2)^3p^2}{3r_1(2r_1+r_2)^2}+\frac{(r_1+2r_2)q^2}{3r_1} \quad . \quad (15)$$

Equation (8), representing a cubic cutting the axis of x in three points, distant $p-q$, p, and $p+q$ respectively, from the origin, may then be written

$$-\frac{6pr_1r_2}{(2r_1+r_2)}y=x^3-3px^2+(3p^2-q^2)x-(p^3-q^2p) \quad . \quad (16)$$

If p be equal to mr_1, q equal to nr_1, and R equal to $\frac{r_2}{r_1}$, m and n being less than unity, equations (13), (14) and (15) may be written respectively,

$$\frac{h}{r_1}=\frac{3(R+1)}{(R+2)}m, \quad . \quad . \quad . \quad . \quad . \quad (17)$$

$$\left(\frac{l_1}{r_1}\right)^2=1-\frac{(R+2)}{3R}(m^2-n^2), \quad . \quad . \quad . \quad (18)$$

and
$$\left(\frac{l_2}{r_2}\right)^2=1-\frac{(2R+1)^3}{3R^2(R+2)^2}m^2+\frac{(2R+1)}{3R^2}n^2 \quad . \quad (19)$$

If R be made infinite, corresponding to the case of a rack and

pinion, equations (17), (18) and (19) may be written respectively,

$$\frac{h}{r_1} = 3m, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (17a)$$

$$\left(\frac{l_1}{r_1}\right)^2 = 1 - \frac{m^2 - n^2}{3}, \quad . \quad . \quad . \quad . \quad (18a)$$

and

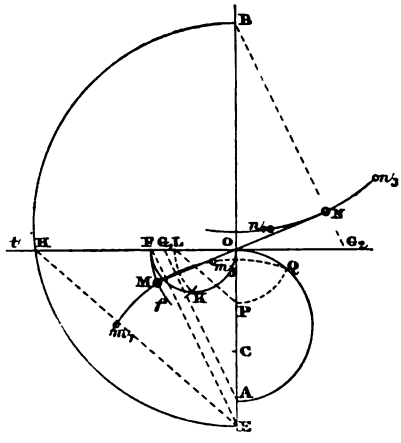
$$\frac{(r_2 - l_2)}{r_1} = \frac{4m^2 - n^2}{3} \quad . \quad . \quad . \quad . \quad (19a)$$

$(r_2 - l_2)$ being the distance of the centres of the circular teeth of the rack from the pitch-line.

The values of $\frac{h}{r_1}$, $\frac{l_1}{r_1}$, and $\frac{l_2}{r_2}$ for different assumed values of R, m and n have been calculated from (17), (18), and (19), and are given in Tables I–III, Appendix IV.

Geometrical Construction.—The following geometrical construction for finding h, l_1, and l_2, having given r_1, r_2, p, and q, will be evi-

Fig. 3.



dent from equations (13), (14) and (15). Let A and B, *Fig. 3*, be the centres of the wheels, O the pitch point, and O t the common tangent to the pitch circles. With centre O, and radius equal to p, draw an arc F f cutting O t in F. Mark off A C equal to one-third A O, and mark C E, towards A, equal to one-third B O. From A and B draw lines parallel to E F determining the points G_1 and G_2 on O t. $G_1 G_2$ is the required value of h. On O F, O A, and E B as diameters, draw semi-circles, that on EB cutting O t in

H. With F as centre, and radius equal to q, draw an arc cutting the semi-circle on F O at K. Mark off along O t, O L equal to O K. Draw L P parallel to H E, cutting A B at P. With centre O and radius O P, draw an arc cutting the semi-circle on A O at Q. A Q is the required value of l_1. With centre A and radius A Q, draw an arc cutting the circle F f in M. Join M O, produce it, and mark off M N equal to $G_1 G_2$. B N is the required value of l_2.

$$\text{For} \quad \frac{G_1 G_2}{A B} = \frac{O F}{O E},$$

i.e.,

$$G_1 G_2 = \frac{(r_1 + r_2)}{\frac{2}{3} r_1 + \frac{1}{3} r_2} p = \frac{3 p (r_1 + r_2)}{(2 r_1 + r_2)} = h, \text{ from (13).}$$

Again, in the right-angled triangles E H O and H B O let $k = \frac{O E}{O H} = \frac{O H}{O B}$, then—

$$k^2 = \frac{O E}{O B} = \frac{2 r_1 + r_2}{3 r_2}, \text{ and } \frac{O E}{O H} = \sqrt{\frac{2 r_1 + r_2}{3 r_2}}.$$

And in the right-angled triangle O K F, $O K = \sqrt{p^2 - q^2} = O L$. Now from similar triangles—

$$\frac{O P}{O L} = \frac{O E}{O H}, \text{ or } \frac{O P}{\sqrt{p^2 - q^2}} = \sqrt{\frac{2 r_1 - r_2}{3 r_2}},$$

i.e.,

$$O P = \sqrt{\frac{(p^2 - q^2)(2 r_1 + r_2)}{3 r_2}}.$$

But

$$A Q^2 = A O^2 - O Q^2 = r_1^2 - \frac{(p^2 - q^2)(2 r_1 + r_2)}{3 r_2} = l_1^2, \text{ from (14).}$$

If from centre O, with radii $p + q$ and $p - q$, arcs be drawn cutting the link circle M Q in m_1 and m_3 respectively, from centres m_1 and m_3, arcs of radius M N be drawn cutting the link circle through N at the points n_1 and n_3 respectively, the straight lines $m_1 n_1$ and $m_3 n_3$ pass through O; a check on the accuracy of the drawing is thus obtained.

Machine-cut Teeth.—If the length of the equivalent link M N be given, from (17) is obtained, writing $L = \frac{h}{r_1}$,

$$m = \frac{R + 2}{3 (R + 1)} L.$$

Substituting in (18) and (19)

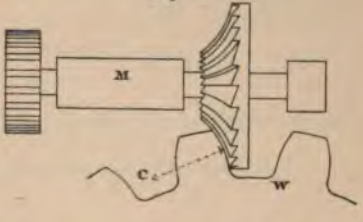
$$\left(\frac{l_1}{r_1}\right)^2 = 1 - \frac{(R+2)^3}{27\,R\,(R+1)^2}\,L^2 + \frac{(R+2)}{3\,R}n^2, \quad (20)$$

and

$$\left(\frac{l_2}{r_2}\right)^2 = 1 - \frac{(2\,R+1)^3}{27\,R^2\,(R+1)^2}\,L^2 + \frac{(2\,R+1)}{3\,R^2}\,n^2 \quad (21)$$

This case is of great practical importance for the manufacture of gear-wheels with teeth formed to their correct outlines by milling-cutters. With a set of a small number of milling-cutters formed to cut circular arcs of different radii, it will be possible to cut any pair of wheels with circular teeth to gear together with practically constant velocity-ratio; the length of the equivalent link in the above formulas being taken equal to the sum of the radii of the two circular milling-cutters used. One set of cutters will suffice for wheels of all diameters and pitches; instead of requiring, as in involute or cycloidal teeth, a separate set of cutters for each pitch. Each side of a tooth, however, must be milled out separately, and the position of the axis of the milling-cutter must be adjustable relatively to the centre of the wheel, both radially and tangentially. One side of every tooth in the wheel would be milled out at one setting of the milling-cutter; after which the cutter would be reversed, and the remaining sides of all the teeth would be milled. Thus, in *Fig. 4*, the part M of the milling-machine carrying the cutter would be adjusted relative to the table on which the wheel W rests, until the distance of C, the centre of the arc of outline of the cutter, from the centre of rotation of the table, was exactly equal to l_1, the required radius of the link circle.

Fig. 4.



Variation of Velocity-Ratio.—Let ρ be the actual velocity-ratio at any instant, then $\rho = \dfrac{r_2 + y}{r_1 - y}$, and the greatest and least velocity ratios will correspond with the maximum and minimum values of y in (16). In an equation of the form

$$b_3 y = a_0 x^3 + a_1 x^2 + a_2 x + a_3,$$

the maximum and minimum values of y are (Appendix III)

$$\frac{1}{9\,a_0\,b_2}\left\{\frac{2\,a_1^3}{3\,a_0}+9\,a_0\,a_3-3\,a_1\,a_2\right\}\pm\frac{2\,(a_1^2-3\,a_0\,a_2)^{\frac{3}{2}}}{27\,a_0^2\,b^2}.$$

Substituting the values of b_2, a_0, a_1, a_2, a_3, from (16), the first term in this expression vanishes, and the maximum and minimum values of y are

$$\pm\frac{\sqrt{3}\,(2\,r_1+r_2)\,q^3}{27\,r_1\,r_2\,p} \quad . \quad . \quad . \quad . \quad (22)$$

Writing $\frac{r_2}{r_1}=\mathrm{R}$, $p=m\,r_1$, $q=n\,r_1$, and $y_{max.}=\mathrm{C}\,r_1$;

$$\mathrm{C}=\frac{0{\cdot}06415\,(\mathrm{R}+2)}{\mathrm{R}}\cdot\frac{n^3}{m} \quad . \quad . \quad . \quad (23)$$

Let the greatest velocity-ratio be denoted by ρ^1, and let R^1 be the greatest excess over the assigned ratio R. Then

$$\rho^1=\mathrm{R}+\mathrm{R}^1=\frac{r_2+\mathrm{C}\,r_1}{r_1-\mathrm{C}\,r_1}=\frac{\mathrm{R}+\mathrm{C}}{1-\mathrm{C}}=(\mathrm{R}+\mathrm{C})(1+\mathrm{C}+\mathrm{C}^2+\ldots)$$
$$=\mathrm{R}+\mathrm{C}\,(\mathrm{R}+1) \quad . \quad . \quad . \quad . \quad . \quad (24)$$

neglecting, since C is a very small fraction, C^2 and higher powers. From (23) and (24)

$$\mathrm{R}^1=\frac{0{\cdot}06415\,(\mathrm{R}+1)\,(\mathrm{R}+2)}{\mathrm{R}}\cdot\frac{n^3}{m}.$$

The variation of the velocity-ratio per cent. will be

$$\frac{100\,\mathrm{R}^1}{\mathrm{R}}=\mathrm{V}=\frac{6{\cdot}415\,(\mathrm{R}+1)\,(\mathrm{R}+2)}{\mathrm{R}^2}\cdot\frac{n^3}{m} \quad . \quad (25)$$

If R be infinite, corresponding to the case of a rack and pinion, (25) becomes

$$\mathrm{V}=6{\cdot}415\,\frac{n^3}{m} \quad . \quad . \quad . \quad . \quad . \quad (25a)$$

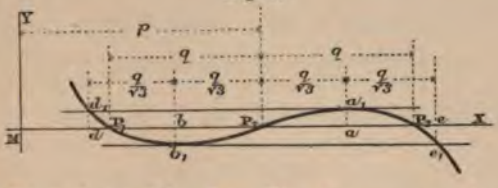
Therefore, in a pair of wheels of given velocity-ratio, having the arc of contact a given multiple of the pitch, the velocity-ratio variation is inversely proportional to the cube of the number of the teeth and inversely proportional to m. The least velocity-ratio $\frac{r_2-\mathrm{C}r_1}{r_1+\mathrm{C}r_1}$ can be easily shown, by the same method, to be equal to $\mathrm{R}-\mathrm{R}^1$, R^1 having the same numerical value as in (25).

The values of V, corresponding with those of R, m, and n in Tables I–IV, Appendix IV, have been calculated from (25), and

no pair of wheels having a velocity variation of 4 per cent. has been tabulated. It will be noticed that the variation is practically negligible when the number of teeth in the smaller wheel is fairly great, as is desirable when any considerable amount of power has to be transmitted. The maximum and minimum velocity-ratios being equally above and below the average, the variation is the least possible for the given arc of contact; and thus the assumption on p. 247 is justified.

Arc of Contact.—In order to secure the longest possible arc of contact of a pair of teeth for the smallest variation of velocity-ratio, the values of the velocity-ratio at the beginning and end of contact should be exactly equal to the maximum and minimum

Fig. 5.



values $R+R^1$ and $R-R^1$. Let *Fig. 5* represent the curve the equation of which is (16), and let $a\,a_1$ and $b\,b_1$ be the maximum and minimum ordinates; through a_1 and b_1 draw lines parallel to M X, cutting the curve in the points d_1 and e_1 respectively, the ordinates of which are $d\,d_1$ and $e\,e_1$. The contact of the pair of teeth should begin and end when the portion M e, *Fig. 2*, of the equivalent link has the values M d and M e, *Fig. 5*, respectively.

The values of M a and M b when the equation to the curve is of the form

$$b_2 y = a_0 x^3 + a_1 x^2 + a_2 x + a_3,$$

are $$\frac{-a_1 \pm (a_1^2 - 3\,a_2\,a_0)^{\frac{1}{2}}}{3\,a_0}$$ (Appendix III).

Substituting the values of a_0 a_1 and a_2 from (16),

$$\text{M } a \text{ and M } b, \textit{Fig. 5}, = p \pm \frac{q}{\sqrt{3}}.$$

Putting $y = a\,a_1 = \dfrac{\sqrt{3}\,(2\,r_1 + r_2)\,q^3}{27\,r_1\,r_2\,p}$ from (22) in (16), a cubic, whose roots are the abscissæ of the points in which the line $d_1\,a_1$ cuts the curve, is obtained. If the coefficient of x^3 in the equation be unity, the sum of the three roots is equal to the coefficient of x^2 with its sign changed, *i.e.*, $3\,p$. Since the line $d_1\,a_1$ touches the

curve at a_1, two of the roots of the cubic are equal to M a, *i.e.*, $= p + \frac{q}{\sqrt{3}}$. The third root, M d, is therefore equal to $3p - 2\left(p + \frac{q}{\sqrt{3}}\right)$, *i.e.*, $p - \frac{2q}{\sqrt{3}}$.

In the same way it may be shown that $Me = p + \frac{2q}{\sqrt{3}}$, and therefore de, the length of the portion of the equivalent link that crosses the line of centres during contact of a pair of teeth, is equal to

$$\frac{4q}{\sqrt{3}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (26)$$

If the obliquity of the equivalent link be neglected, the arc of contact measured along the pitch line will also be approximately $\frac{4q}{\sqrt{3}}$, and if the arc of contact be equal to the pitch, N, the number of teeth in the small wheel, will be

$$\frac{2\pi r_1}{\frac{4q}{\sqrt{3}}} \text{ or } \frac{\sqrt{3}\,\pi}{2n}.$$

However, the velocity-ratio changes much more rapidly at d and e, *Fig. 5*, than at any intermediate point during contact, so that it will be better to make contact begin and end where the velocity-ratio is exactly equal to the assigned value R. In this case

$$N = \frac{2\pi r_1}{2n r_1} = \frac{\pi}{n} \quad . \quad . \quad . \quad . \quad . \quad (27)$$

The values of N in the Tables, Appendix IV, have been calculated from (27). A curve of velocity-ratio of the pair of wheels will now be a continuous sinuous line. In the former case there would be a sudden jump from the maximum to the minimum value, or *vice versa*, as one pair of teeth left and another pair came into contact. The arc of contact measured along the pitch-line will actually be slightly greater than the value given above, so the error introduced is on the safe side.

Obliquity of Action of Teeth.—From (25) the amount of velocity-ratio variation is inversely proportional to m, and will therefore be smaller the larger p is taken. The larger p is, however, the greater the obliquity of the equivalent link, and therefore the greater the obliquity of action of the teeth. A superior limit to the value of p is thus fixed by practical considerations.

The values of ϕ, the maximum angle of obliquity, for R = 1, 3, and 10, are given in Tables I–III; for intermediate values of R, ϕ may be determined by interpolation, or direct from the diagram, *Fig. 6*, in which r_1 is taken equal to unity, and a series of concentric link-circles are drawn, the radii l_1 of each being denoted by the corresponding figure on the line A O. The circles of radii $(m + n)$ and $(m - n)$ respectively, and with the pitch point O as centre, will cut off the portion of the link-circle actually used during contact of a pair of teeth. By drawing a series of lines through the pitch point at different angles with the common tangent O t, the maximum obliquity of action of a given pair of teeth can be seen at once. As an example, the link-circle $m_1\ m_2\ m_3$ of a pair of wheels in which R = 3, $m = 0{\cdot}3$, and $n = 0{\cdot}25$, is shown by a dotted line. From Table II, $l_1 = 0{\cdot}992\, r_1$; and from *Fig. 6* the maximum obliquity of action of the teeth is 16·7°.

Examples.—The following example will illustrate the method of using the Tables I–III for any case that may arise. A pair of wheels are required with ninety-six and thirty teeth respectively, diametral pitch (*i.e.*, ratio of the number of teeth to the diameter of the wheel in inches) 1, arc of contact $1\frac{1}{4}$ times the pitch. The diameters of the pitch-circles will be 96 inches and 30 inches. Using Table II (*i.e.*, taking $m = 0{\cdot}3$), and noting that R = 3·2, by interpolation

$$\frac{h}{r_1} = 0{\cdot}726\,;\ \textit{i.e.},\ h = 0{\cdot}726 \times 15 = 10{\cdot}89 \text{ inches.}$$

Since the arc of contact is required to be $1\frac{1}{4}$ times the pitch, N will be $\frac{30}{1\frac{1}{4}} = 24$. Noting that the values of $\frac{l_1}{r_1}$ change very slowly as N increases, by interpolation, when N = 24, the values of $\frac{l_1}{r_1}$ for R = 3 and 4 are 0·980 and 0·981 respectively; from which the value of $\frac{l_1}{r_1}$ for R = 3·2 may be taken 0·980. In the same way $\frac{l_2}{r_2} = 0{\cdot}981$.

Therefore $l_1 = 0{\cdot}980 \times 15 = 14{\cdot}70$ inches,

and $l_2 = 0{\cdot}981 \times 48 = 47{\cdot}09$ inches.

Also $p = 0{\cdot}3\, r_1 = 4{\cdot}5$ inches,

and $\frac{q}{r_1} = 0{\cdot}12$, or $q = 0{\cdot}12 \times 15 = 1{\cdot}8$ inch.

V, the variation of the velocity-ratio, is about 0·1, *i.e.*, one-tenth of 1 per cent.

Fig. 6.

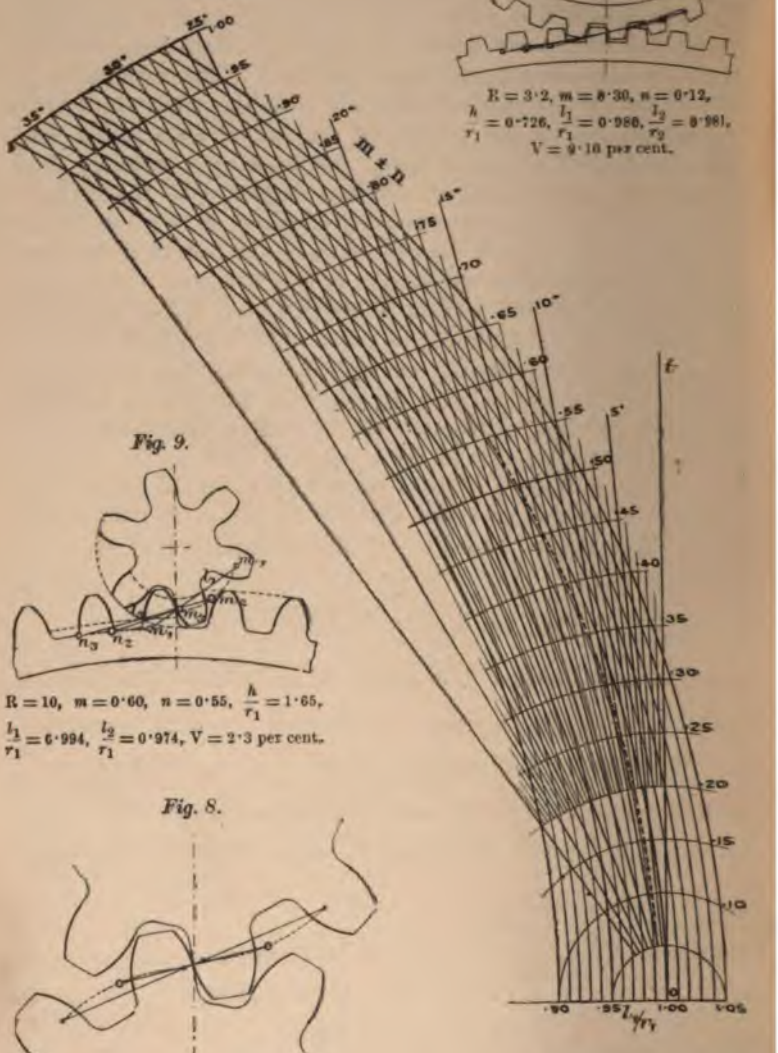
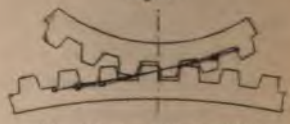


Fig. 7.



R = 3·2, $m = 0·30$, $n = 0·12$,
$\frac{h}{r_1} = 0·726$, $\frac{l_1}{r_1} = 0·988$, $\frac{l_2}{r_2} = 0·981$,
V = 9·16 per cent.

Fig. 9.

R = 10, $m = 0·60$, $n = 0·55$, $\frac{h}{r_1} = 1·65$,
$\frac{l_1}{r_1} = 6·994$, $\frac{l_2}{r_1} = 0·974$, V = 2·3 per cent.

Fig. 8.

R = 1, $m = 0·40$, $n = 0·35$, N = 9,
$\frac{h}{r} = 0·80$, $\frac{l}{r} = 0·981$, V = 4·1 per cent.

The forms of the teeth (the arcs of approach and recess being taken equal) are shown in *Fig. 7*; the positions of the ends of the equivalent link when the velocity-ratio is exactly equal to its assigned value (that is, at beginning, middle, and end of contact) are shown by small circles. *Fig. 8* illustrates an extreme case; two equal wheels, each with nine circular teeth, from Table III. The variation of velocity-ratio is 4·1 per cent. The circular part of each tooth is shown thickened, the remainder near the root not having contact with the other wheel. *Fig. 9* also shows an extreme case, a wheel and pinion of sixty and six teeth respectively, with $m = 0{\cdot}6$, and $n = 0{\cdot}55$. The variation is 2·3 per cent. of the average velocity-ratio. Here again the circular part of each tooth is shown thickened. In *Fig. 10* is shown a rack and seven-toothed pinion; $m = 0{\cdot}2$, $n = 0{\cdot}45$. The velocity-ratio variation is 2·9 per cent.

Fig. 10.

$R = \infty$, $m = 0{\cdot}20$, $n = 0{\cdot}45$, $N = 7$, $\frac{h}{r_1} = 0{\cdot}600$, $\frac{l_1}{r_1} = 1{\cdot}027$, $\frac{r_2 - l_2}{r_1} = 0{\cdot}014$, V = 2·9 per cent.

Special Solution.—In the solution given in the Paper on "A New Method of Designing Wheel Teeth," [1] the roots of equation (3) are of the form

$$r_1 \sin \phi + \frac{3q}{2},\ r_1 \sin \phi + \frac{q}{2},\ r_1 \sin \phi - \frac{q}{2},$$

i.e., p is assumed equal to

$$r_1 \sin \phi + \frac{q}{2} \quad . \quad . \quad . \quad . \quad . \quad (28)$$

Also h is assumed equal to

$$(r_1 + r_2) \sin \phi.$$

Substituting these values of p and h in (10),

$$\sin \phi = \frac{3q}{2(r_2 - r_1)} \quad . \quad . \quad . \quad . \quad (29)$$

The determination of the mean angle of obliquity by equation (29) dispenses with the trial and error process in the solution referred to above.

[1] Minutes of Proceedings Inst. C.E., vol. cxiii. p. 241.

From (28) and (29), by writing $p = m r_1$ and $q = n r_1$,

$$\frac{m}{n} = \frac{2 r_1 + r_2}{2 (r_2 - r_1)} = \frac{(\mathrm{R} + 2)}{2 (\mathrm{R} - 1)},$$

Substituting in (25)

$$\mathrm{V} = 12{\cdot}83 \frac{(\mathrm{R} + 1) (\mathrm{R} - 1)}{\mathrm{R}^2} n^2 \quad . \quad . \quad . \quad (30)$$

i.e., in a pair of wheels of given velocity-ratio and having the arc of contact of the teeth a given multiple of the pitch, the velocity-ratio variation is inversely proportional to the square of the number of teeth.

In the pair of wheels shown in *Figs. 5*, *6*, and *7* of the Paper referred to,[1] which have fifteen and thirty teeth respectively, and an arc of contact 1·06 of the pitch, neglecting the difference of the arcs of contact as measured along the pitch and link circles,

$$\frac{4q}{\sqrt{3}} = \frac{4 n r_1}{\sqrt{3}} = \frac{1{\cdot}06 \cdot 2 \pi r_1}{15},$$

i.e.,

$$n = \frac{1{\cdot}06 \sqrt{3} \pi}{30} = 0{\cdot}194.$$

Substituting in (30)

$$\mathrm{V} = 0{\cdot}36.$$

That is, the maximum and minimum velocity-ratios are 2·007 and 1·993 respectively; which results agree very closely with the values 2·006 and 1·992 determined by measurement from the drawing.

Internal Gear.—With internal gearing the radius of the larger wheel may be considered negative, and the value of R will also be negative. Substituting $\mathrm{R} = -\mathrm{R}$ in equations (17), (18), (19), and (25), they become respectively—

$$\frac{h}{r_1} = \frac{3 (\mathrm{R} - 1)}{(\mathrm{R} - 2)} m \quad . \quad . \quad . \quad . \quad . \quad (17\mathrm{b})$$

$$\left(\frac{l_1}{r_1}\right)^2 = 1 - \frac{(\mathrm{R} - 2)}{3 \mathrm{R}} (m^2 - n^2) \quad . \quad . \quad . \quad (18\mathrm{b})$$

$$\left(\frac{l_2}{r_2}\right) = 1 + \frac{(2 \mathrm{R} - 1)^3 m^2}{3 \mathrm{R}^2 (\mathrm{R} - 2)^2} - \frac{(2 \mathrm{R} - 1)}{3 \mathrm{R}^2} n^2 \quad . \quad (19\mathrm{b})$$

$$\mathrm{V} = \frac{6{\cdot}415 (\mathrm{R} - 1) (\mathrm{R} - 2)}{\mathrm{R}^2} \cdot \frac{n^3}{m} \quad . \quad . \quad (25\mathrm{b})$$

[1] Minutes of Proceedings Inst. C.E., vol. cxiii. p. 245.

In particular, if $\mathsf{R} = 2$,

$$\frac{h}{r_1} = \infty, \frac{l_1}{r_1} = 1, \frac{l_2}{r_2} = \infty, \text{ and } \mathrm{V} = 0.$$

That is, in this case the variation of velocity-ratio is zero, the centres of the circular arcs forming the outlines of the teeth of the small wheel lie on the pitch-circle, and the tooth-outlines of the larger wheel are straight lines; that is, circular arcs with their centres at infinity. This is exactly the same as the well-known special case of internal gearing with cycloidal teeth, the velocity-ratio being $\mathsf{R} = 2$, and the rolling-circle being equal to the pitch-circle of the smaller wheel. The teeth of the small wheel become points, and the teeth of the larger wheel straight lines, diameters of the pitch-circle; or curves parallel to these may be used, the teeth of the small wheel become circular pins, and the spaces between the teeth of the larger wheel diametral slots.

If $\mathsf{R} < 2$, from (17*b*), $\frac{h}{r_1}$ becomes negative; that is, the equivalent link in its middle position $m_2 n_2$ lies entirely on one side of

Fig. 11.

R = 1·5, m = 0·4, n = 0·3, V = 0·05 per cent.

the pitch point O. If the arcs of approach and recess be made equal (that is, the tooth-outlines be made to pass through the pitch point when the equivalent link is in its middle position) the teeth of the small wheel will be convex, and those of the larger wheel concave, as in *Fig. 11*. In the pair of wheels shown in *Fig. 11*, $\mathsf{R} = 1\frac{1}{2}$, $m = 0{\cdot}4$, $n = 0{\cdot}3$, N (the number of teeth in the small wheel) = 10, and V (the variation of velocity-ratio) = 0·05 per cent.

If $\mathsf{R} > 2$, $\frac{h}{r_1}$ is positive, and the arcs of approach and recess being equal the teeth of both wheels will be convex, *Fig. 12*.

In the pair of wheels shown in *Fig. 12*, R = 3, $m = 0{\cdot}4$, $n = 0{\cdot}8$, N (the number of teeth in the small wheel) = 4, and V (the variation of velocity-ratio) = 1·8 per cent.

The values of $\frac{h}{r_1}$, $\frac{l_1}{r_1}$, $\frac{l_2}{r_2}$, and V, given in Table I*b*, Appendix IV, have been calculated from (17*b*), (18*b*), (19*b*), and (25*b*). The

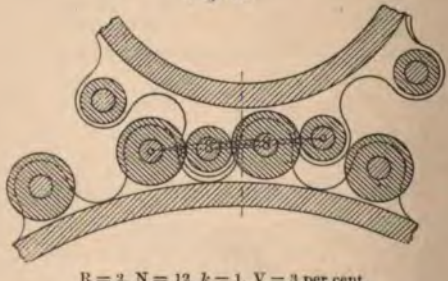
Fig. 12.

R = − 3, $m = 0{\cdot}4$, $n = 0{\cdot}8$, $\frac{h_1}{r_1} = 2{\cdot}4$, $\frac{l_1}{r_1} = 1{\cdot}027$, $\frac{l_2}{r_2} = 1{\cdot}274$, V = 1·8 per cent.

very small values of V, even when the smaller wheel has an extremely small number of teeth, may be particularly noted.

Roller-and-pin Wheels.—Fig. 13 shows a pair of wheels in which the circular teeth are replaced by complete circular rollers of the

Fig. 13.

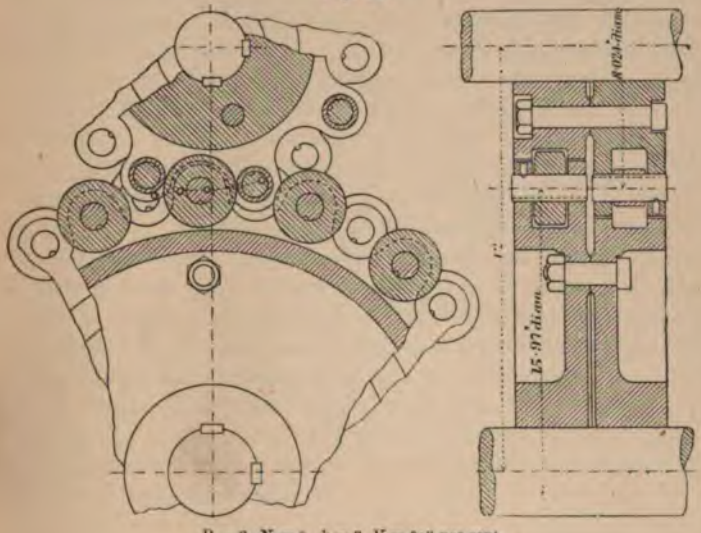


R = 2, N = 12, $k = 1$, V = 3 per cent.

same radius, turning on cylindrical pins. The length h of the equivalent link is the sum of the radii of the two rollers. If the wheels are required to have no side clearance each roller of one

wheel as it crosses the line of centres will touch two rollers of the other. If the teeth engaged deeply, so that the roller of one wheel came in line with the two adjacent rollers of the other, the sum of the diameters of the two rollers would need to be exactly equal to the smaller side of the pitch-polygons of the pins, if there was no side clearance. (The polygonal pitch of the pins will not, in general, be the same for the two wheels.) The sum of the diameters of the two rollers may be taken less than the smaller polygonal pitch of the pins, in which case there will be side clearance. For a pair of wheels with a given number of

Fig. 14.



R = 2, N = 8, k = 2, V = 0·3 per cent.

Scale, $\frac{3}{16}$ full size.

ROLLER-AND-PIN WHEELS.

rollers, the velocity-ratio variation will be less if the rollers are arranged so as to form a pair of stepped wheels, *Fig. 14*, than if they are arranged as in *Fig. 13*. In *Fig. 14*, each wheel is made up of two steps, the pin of one step being placed midway between two adjacent pins of the other; the arc of contact is approximately equal to half the pitch of the pins. There are eight and sixteen teeth respectively in a pair of steps, so that the complete pair of wheels is equivalent to spur-wheels with sixteen and thirty-two circular teeth.

Circular pins have been used instead of teeth, when the wheels

are equal and turn in the same direction, *i.e.*, R = − 1 ; also in one wheel of a pair, the outline of the teeth of the other wheel being a curve parallel to an epicycloid; but with these exceptions circular pins or rollers have never before, to the Author's knowledge, been proposed for the teeth of spur-wheels. Such wheels are interesting from a mechanical point of view, in so far as the relative sliding of the higher pair in spur-wheel teeth, is here replaced by the relative turning of two lower pairs (the rollers and pins); the relative motion of the surfaces in rubbing contact being less in the latter than in the former case. The roller and pin, forming a cylindrical journal, can be much better lubricated than the teeth of spur-wheels; and since they have surface contact, as against line contact of spur-wheels, the frictional resistance and the wear is greatly reduced. Even assuming that the lubrication of the rollers is so imperfect that they stick on their pins, and that, therefore, the rollers of one wheel rub on those of the other, they will at least be moved slowly round on their pins; and the wear will be distributed round their entire outer surfaces, instead of being confined, as in fixed teeth, to small parts of the surfaces in the neighbourhood of the pitch lines.

If the rollers are made of hard steel, it seems that the power that may safely be transmitted, may be very much higher than would be possible with a pair of ordinary spur-wheels of the same size. Again, with pins of wrought-iron or mild steel large wooden rollers might be used on the large wheel; this would give the easy, noiseless running of mortise wheels with a much stronger, though perhaps more costly, construction.

Let N be the number of teeth in one step of the smaller wheel, and k the number of steps. Then it may be assumed, provisionally $h = \frac{2\pi r_1}{2N}$, that is,

$$\frac{h}{r_1} = L = \frac{\pi}{N} \quad . \quad . \quad . \quad . \quad . \quad (31)$$

Substituting this value of h in (17),

$$m = \frac{p}{r_1} = \frac{(R+2)\,\pi}{3(R+1)N} \quad . \quad . \quad . \quad . \quad (32)$$

If one pair of teeth comes into contact as the previous pair leaves, the arc of contact is approximately,

$$2q = \frac{2h}{k} = \frac{2\pi r_1}{Nk};$$

$$n = \frac{\pi}{Nk} \quad . \quad . \quad . \quad . \quad . \quad . \quad (33)$$

Substituting the values of L and n from (31) and (33) in (20) and (21) respectively.

$$\left(\frac{l_1}{r_1}\right)^2 = 1 - \frac{(R+2)^3}{27\,R\,(R+1)^2}\frac{\pi^2}{N^2} + \frac{(R+2)\,\pi^2}{3\,R\,N^2 k^2} \quad . \quad (34)$$

$$\left(\frac{l_2}{r_2}\right)^2 = 1 - \frac{(2R+1)^3}{27\,R^2(R+1)^2}\frac{\pi^2}{N^2} + \frac{(2R+1)}{3\,R^2}\frac{\pi^2}{N^2 k^2} \quad (35)$$

Substituting the values of m and n from (32) and (33) in (25).

$$V = 19{\cdot}24\,\frac{(R+1)^2}{R^2}\frac{\pi^2}{N^2 k^3} \quad . \quad . \quad . \quad (36)$$

If R be made infinite, corresponding with the case of a rack and pinion, equations (32), (34), (35), and (36), may be severally written

$$m = \frac{p}{r_1} = \frac{\pi}{3N} \quad . \quad . \quad . \quad . \quad . \quad . \quad (32a)$$

$$\left(\frac{l_1}{r_1}\right)^2 = 1 - \frac{\pi^2}{27\,N^2}\left(1 - \frac{9}{k^2}\right) \quad . \quad . \quad . \quad (34a)$$

$$\frac{r_2 - l_2}{r_1} = \frac{\pi^2}{27\,N^2}\left(4 - \frac{9}{k^2}\right) \quad . \quad . \quad . \quad . \quad (35a)$$

$$V = 19{\cdot}24\,\frac{\pi^2}{N^2 k^3} \quad . \quad . \quad . \quad . \quad . \quad (36a)$$

From (36a) the velocity-ratio variation in a rack and pinion of forty rollers, as might be used for a rack railway, will be 0·12 per cent. for $k = 1$, and 0·01 per cent. for $k = 2$.

Table IV, Appendix IV, has been calculated from equations (34), (35), and (36), and no pair of wheels has been tabulated in which V exceeds 4 per cent.

The assumed value of h is subject to the condition that the rollers can pass the line of centres, as above discussed. Now it will be found, on drawing a pair of roller-and-pin wheels from the figures in Table IV, that the length h from (31) is in general, either a little too great, so that the rollers jam in crossing the line of centres, or slightly less than might be allowed, so that there is a small amount of side clearance. In the latter case no correction is in general necessary, but in the former case h must be taken a little smaller, and corrected values for $\frac{l_1}{r_1}$ and $\frac{l_2}{r_2}$ determined by substitution in (20) and (21). However, for the small change of h, necessary for the rollers to clear, the change in the values of $\frac{l_1}{r_1}$ and $\frac{l_2}{r_2}$ for the cases tabulated is so small that the

last figure tabulated is not affected by one unit, unless the number of rollers is very small. This can be shown as follows: From (20) by differentiation,

$$\frac{l_1 d l_1}{r_1^2} = -\frac{(R+2)^3 L}{27 R (R+1)^2} d L.$$

$\frac{l_1}{r_1}$ does not differ much from unity, and writing for L its value in (31), the above equation may be written,

$$\Delta \frac{l_1}{r_1} = -\frac{(R+2)^3}{27 R (R+1)^2} \frac{\pi}{N} \Delta L \quad . \quad . \quad . \quad (37)$$

the increment ΔL being so small that $\frac{\Delta l_1}{\Delta L}$ does not sensibly differ from $\frac{d l_1}{d L}$. In the same way,

$$\Delta \frac{l_2}{r_2} = -\frac{(2R+1)^3}{27 R^2 (R+1)^2} \frac{\pi}{N} \Delta L \quad . \quad . \quad . \quad (38)$$

Writing (37) and (38) respectively in the forms

$$\Delta \frac{l_1}{r_1} = -\frac{C_1}{N} \Delta L, \quad \Delta \frac{l_2}{r_2} = -\frac{C_2}{N} \Delta L,$$

the values of C_1 and C_2 are as follows:—

R =	1·00	1·50	2·00	4·00	10·00
C_1 =	0·78	0·53	0·41	0·25	0·17
C_2 =	0·78	0·53	0·40	0·21	0·09

In the pair of wheels shown in *Fig. 14*, in order that the rollers may pass the line of centres without jamming, ΔL is $-0{\cdot}01$, $\Delta \frac{l_1}{r_1} = -0{\cdot}0005$, and $\Delta \frac{l_2}{r_2} = -0{\cdot}0005$; *i.e.*, the changes in the values of $\frac{l_1}{r_1}$ and $\frac{l_2}{r_2}$ respectively, are less than the change produced by altering by one unit the last figure tabulated.

The values given in Table IV will serve for a first trial, from which a closer approximation to h than that assumed (31) can be obtained. This value of h being substituted in (20) and (21), more exact values of $\frac{l_1}{r_1}$ and $\frac{l_2}{r_2}$ are obtained.

Internal Gear with Roller-and-Pin Wheels.—If $\mathsf{R} = -\mathrm{R}$ equations (32), (34), (35), and (36) may be severally written,

$$m = \frac{p}{r_1} = \frac{(\mathsf{R}-2)\pi}{3(\mathsf{R}-1)\mathrm{N}} \quad . \quad . \quad . \quad . \quad (32b)$$

$$\left(\frac{l_1}{r_1}\right)^2 = 1 - \frac{(\mathsf{R}-2)\pi^2}{27\,\mathsf{R}\,\mathrm{N}^2}\left\{\frac{(\mathsf{R}-2)^2}{(\mathsf{R}-1)^2} - \frac{9}{k^2}\right\} \quad . \quad (34b)$$

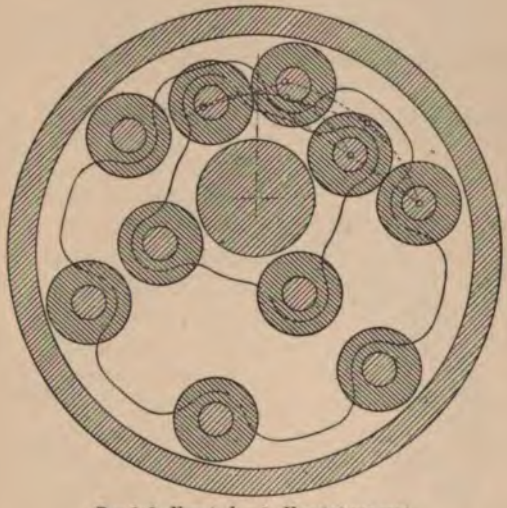
$$\left(\frac{l_2}{r_2}\right)^2 = 1 + \frac{(2\,\mathsf{R}-1)\pi^2}{27\,\mathsf{R}^2\mathrm{N}^2}\left\{\frac{(2\,\mathsf{R}-1)^2}{(\mathsf{R}-1)^2} - \frac{9}{k^2}\right\} \quad . \quad (35b)$$

$$\mathrm{V} = 19{\cdot}24\frac{(\mathsf{R}-1)^2\pi^2}{\mathsf{R}^2\mathrm{N}^2k^3} \quad . \quad . \quad . \quad . \quad (36b)$$

Table IV *b* has been calculated from these equations.

If R is less than 2 but greater than 1, m is negative; and if the

Fig. 15.

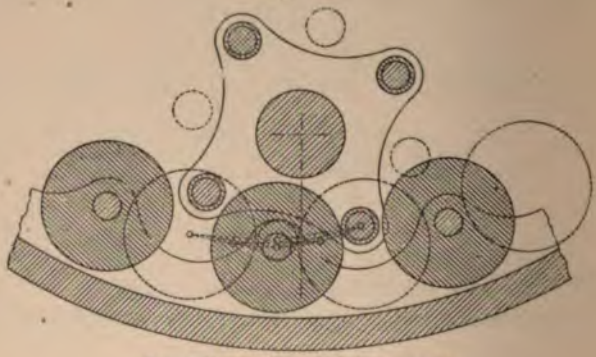


$\mathsf{R} = 1{\cdot}5$, $\mathrm{N} = 4$, $k = 1$, $\mathrm{V} = 1{\cdot}3$ per cent.

rollers have external contact (as is necessary so that they may recede from each other when outside the defined range of action) the arcs of approach and recess will be unequal. *Fig. 15* shows a pair of roller-and-pin wheels with internal contact; $\mathsf{R} = 1{\cdot}5$, $\mathrm{N} = 4$, $k = 1$, $\mathrm{V} = 1{\cdot}3$ per cent. The path of contact lies almost entirely on one side of the line of centres. If $\mathsf{R} = 2$, $m = 0$, and if the arcs of approach and recess are required to be equal, one roller degenerates to a point. If R is greater than 2, m is positive,

and the arcs of approach and recess can be made equal. *Fig. 16* shows a pair of stepped roller-and-pin wheels with internal contact,

Fig. 16.

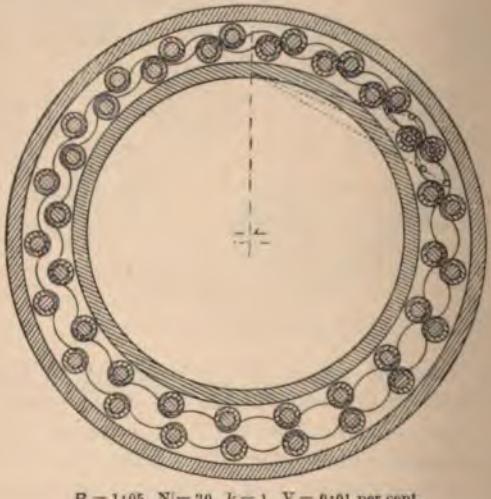


R = 4, N = 4, $k = 2$, V = 0·83 per cent.

R = 4, $k = 2$, N = 4, V = 0·83 per cent.; the pins and rollers of one step being shown in full lines, the rollers of the other step dotted.

An interesting case in internal gearing is that in which the

Fig. 17.



R = 1·05, $N_1' = 20$, $k = 1$, V = 0·01 per cent.

velocity-ratio does not differ much from unity. *Fig. 17* shows a pair of roller-and-pin wheels with twenty and twenty-one teeth

respectively; R = 1·05, N = 20, k = 1; equations (31), (32b), (33), (34b), (35b), (36b) give the following values: $\frac{h}{r_1}$ = 0·157, m = − 0·995, n = 0·157, $\frac{l_1}{r_1}$ = 1·136, $\frac{l_2}{r_2}$ = 1·198, and V = 0·01 per cent. The side clearance between the rollers is here much greater than is necessary. Assume another value of $\frac{h}{r_1}$, say 0·17. Substituting in (19a), (20), and (21), m = 1·077, $\frac{l_1}{r_1}$ = 0·159, and $\frac{l_2}{r_2}$ = 1·221. *Fig. 17* is drawn to these dimensions, the rollers of one wheel just being able to pass clear of those of the other. This example demonstrates that in internal gear with roller-and-pin wheels the equivalent four-link mechanism must satisfy another condition, viz., the equivalent cranks connected by the equivalent link must oscillate, and not perform complete revolutions. Therefore $(r_1 + l_1 + h)$ must not be greater than $(r_2 + l_2)$, otherwise the rollers could not clear each other when farthest away from the pitch-point, and the gear would be impossible.

Special Tooth Forms.—Any point on the equivalent link may be taken as the point through which the two circular arcs forming the tooth-outlines are drawn. The ratio of the arcs of approach and recess depend on the position of this point. In the wheels illustrated in *Figs. 7*, *8*, *9*, *10*, *11*, *12*, *13*, *14* and *16*, when the equivalent link is in its mean position, the circular arcs pass through the pitch point; that is, the arcs of approach and recess are equal. Special tooth-forms may be obtained by choosing the point L, *Fig. 1*, in other positions along the equivalent link. In particular, if L coincide with M, *Fig. 1*, the teeth of one wheel degenerate to points, while those of the other are circular arcs of radius equal to the length of the equivalent link. *Fig. 18* shows a pair of wheels in which the point M is so taken that the teeth of one wheel may be circular pins, giving a form resembling in general appearance the well-known special case in cycloidal wheel-teeth. The pin in this case again may be surrounded by a circular roller which will roll on the tooth of the other wheel.

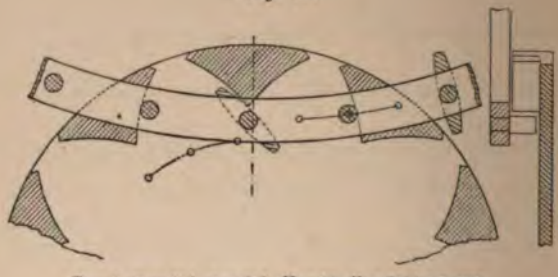
Fig. 18.

R = 1, m = 0·4, n = 0·35, N = 9, V = 4·1 per cent.

The wheels, *Fig. 18*, differ only from those in *Fig. 8*, in the arcs of approach and recess being unequal.

If the point L be taken on the equivalent link M N produced, the mechanism shown in *Fig. 19* is obtained. Here the teeth of one

Fig. 19.



R = ?, $m = 0{\cdot}4$, $n = 0{\cdot}3$, N = 10. V = 0·81 per cent.

wheel are circular pins projecting from a ring or disk; the teeth of the other wheel project from a flat disk, and are so formed that on approaching the line of centres each circular pin passes inside the teeth of the other wheel, passes from one side of the corresponding tooth to the other, and then moves outwards. The corresponding case in cycloidal gearing is well known. In both cases the path of the point of contact L lies at some distance from the pitch point.

"*Lower Pair*" *Toothed Wheels.*—From the fact that the tooth-outlines are circular arcs, it is possible to make a pair of wheels with only lower pairs. Such a pair of wheels is derived from a pair, one of which has circular-pin teeth. Thus in *Fig. 18*, the circular pins, instead of having circular rollers surrounding them may have slide-blocks, the rubbing surfaces of which are curved to the same radius as the teeth on which they slide, *Fig. 20*. The mechanism of such a wheel consists only of lower pairs; that is, the different parts have contact along a surface instead of along a line, as in the teeth of ordinary spur-wheels. During the time of contact of a pair of teeth, made as in *Fig. 20*, the slide-block will rotate on the pin.

Fig. 20.

R = 10, $m = 0{\cdot}4$, $n = 0{\cdot}55$,
V = 3·5 per cent.

The slide-block must be guided properly so as to enter the gap between two adjacent teeth as it comes into gear. The angle through which each slide-block must move is of definite amount; and if the further rotation be prevented, as shown in *Fig. 20*, they can be correctly guided by the teeth of the other wheel, so as to enter the tooth-spaces properly. The mechanism of *Fig. 19* may also be formed into a lower pair mechanism, by the use of slide-blocks on circular pins, two of which are shown in the *Fig.*

Error in Tooth-Outlines.—The magnitude of the error involved by the use of circular teeth, may be better expressed by stating the greatest distance between the circular arcs and the outlines of a pair of teeth which will give *exactly* constant velocity-ratio. It has been already shown that the excess of the velocity is proportional to y; *Fig. 5*, therefore, is a curve representing the excess of velocity, drawn to a 'space' base. If the velocity varies only slightly during the period considered, this curve will not differ much from that drawn to a 'time' base. Taking the origin at the middle point of intersection of the curve with MX, and denoting aa_1, the maximum value of y, by y_0, the equation of the curve can be shown to be

$$y = \frac{3\sqrt{3}\,y_0}{2q^3}(q^2 - x^2)\,x \quad . \quad . \quad . \quad . \quad (39)$$

The area of the segment $P_2\,a_1\,P_3$ can be shown to be

$$\frac{3\sqrt{3}}{8}\,q\,y_0;$$

hence the *average* excess during the first portion of contact, or *average* deficiency during the second portion, is $\frac{3\sqrt{3}}{8}$ (*i.e.*, 0·650) of the maximum. With an arc of contact equal to the pitch, and maximum velocity-variation 1 per cent., during the first part of contact, the driven tooth will have moved a distance $\frac{0{\cdot}0065}{2}$ of the pitch further than if the velocity-ratio had been constant. Let *Fig. 21* represent the outlines of a pair of circular teeth, P_1, P_2, P_3, and P_1', P_2', P_3', being the points of contact corresponding with P_1, P_2, P_3, *Fig. 5*. Then retaining the tooth-outline P_1', P_2', P_3', that of a tooth to give exactly constant velocity-ratio will be represented by the dotted curve lying $\frac{0{\cdot}0065}{4}$ the pitch outside P_1 and P_3, and the same distance inside at P_2. This difference may be divided between the two teeth; the full lines, *Fig. 22*, representing the circular teeth, and the dotted lines the exact tooth

forms. The greatest difference between the outlines is now $\frac{0{\cdot}0065}{8}$ (*i.e.*, 0·0008) of the pitch.

Thus the error in circular teeth giving a variation of velocity-ratio of 1 per cent. is less than one-thousandth of the pitch. The

Fig. 21.

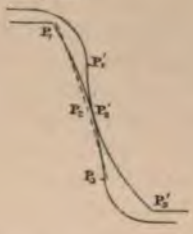
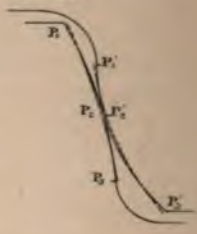


Fig. 22.



error of the circular teeth shown in *Fig. 7*, is 0·0008 × 0·1, or 0·00008, of the pitch. These errors, in the case of wheels with fairly large numbers of teeth, are much smaller than those of the most perfect workmanship possible.

Bevil Wheels.—The same general principles may be applied to the design of the teeth of bevil-wheels, the working surfaces of the teeth being portions of right circular cones whose common vertex coincides with that of the pitch-cones. The four-link plane mechanism of *Fig. 2* will be replaced by a four-link spheric mechanism. The equations expressing the conditions that the velocity-ratio of the spheric cranks is exactly equal to the assigned value at three nearly equidistant positions, are different in form from the corresponding equations for cylindrical wheels, and may form the subject of a separate investigation. If in each wheel the angular radius of the pitch-cone does not differ much from the angular distance between the axes of the tooth- and pitch-cones, and if the angle of the spheric equivalent link is small, no great error will be made by drawing the tooth-form of each wheel on the cone which touches the sphere at its circle of intersection with the pitch-cone. Drawing, as in the usual method of designing bevil-wheels, the developments of the two tangent cones, the problem is reduced to designing a pair of cylindrical wheels, and the equations given above can be used.

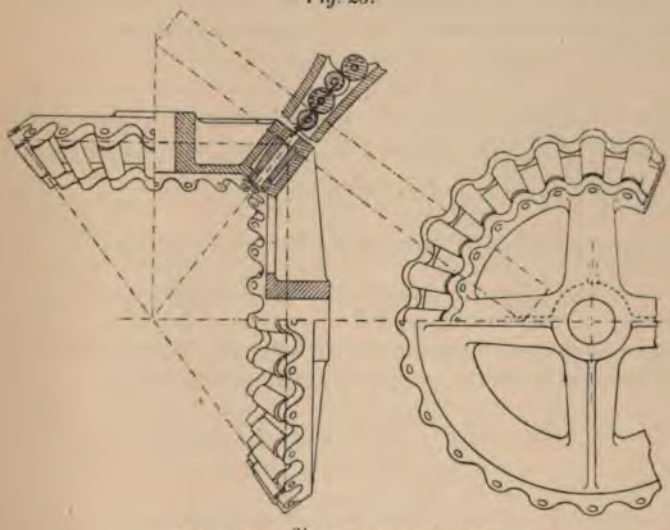
In the case of a pair of bevil-wheels with axes at right-angles, if t_1 and t_2 be the numbers of teeth in the wheels, r_1 and r_2 the radii of the developed pitch-circles of the tangent cones,

$$\mathrm{R} = \frac{r_2}{r_1} = \left(\frac{t_2}{t_1}\right)^2, \quad \mathrm{N} = \frac{t_1}{t_2}\sqrt{{t_1}^2 + {t_2}^2} \quad . \quad . \quad (40)$$

The values of R and N in (40) must be taken, in using Tables I-IV for bevil-wheels with shafts at right-angles. *Fig. 23* shows a pair of bevil-wheels with roller-and-pin teeth; the numbers of teeth being eighteen and twenty-four respectively. In the development, $R = \left(\frac{24}{18}\right)^2 = \frac{16}{9}$, $N = 22{\cdot}5$ and $k = 1$. From Table IV, $\frac{l_1}{r_1} = 1{\cdot}005$, $\frac{l_2}{r_2} = 1{\cdot}003$ and $\frac{h}{r_1} = 0{\cdot}140$; from (32) and (33) $m = 0{\cdot}063$ and $n = 0{\cdot}140$. The variation of the velocity-ratio, from (36), is 0·9 per cent.

Roller-and-pin teeth, or simply conical-pin teeth, for bevil-

Fig. 23.



Velocity-Ratio $\frac{24}{18}$. Variation, 0·9 per cent.

ROLLER-AND-PIN BEVIL-WHEELS.

wheels, have some important properties to recommend them. While it is a comparatively simple process to cut the teeth of cylindrical wheels to any required shape by milling-tools, the correct form can only be given to bevil-wheel teeth by planing. During each stroke of the planing-tool, the cutting point should move in a straight line passing through the vertex of the pitch-cone. This necessitates a special machine, and adds so considerably to the cost of manufacture that machine-cut bevil-wheels have been very little used. Conical rollers can easily be accurately turned; the pins may be cylindrical, fitting tightly in cylindrical holes drilled

in the wheel. The drilling of these holes at exactly equal intervals, with their axes all intersecting at the vertex of the pitch-cone presents no particular difficulty and requires no special machine. Besides the advantages of diminution of friction and wear, these roller-and-pin bevil-wheels should compare favourably with machine-cut bevil-wheels in regard to cost of manufacture.

Degree of Approximation used in calculating Velocity-Ratio.—In the foregoing investigation the values of l_1, l_2, and h as determined by equations (17), (18), and (19) are exact, and are applicable whatever be the values of p and q. In calculating V, the maximum variation from the assigned velocity-ratio, an approximation to the value of the coefficient of y has been used, and powers of y higher than the first have been neglected. An error is thus introduced, the magnitude of which can be investigated as follows.

Equation (1) may be written in full

$$\begin{aligned}(r_1+r_2)\,x^3-(2\,r_1+r_2)\,h\,x^2+[r_1\,(r_2{}^2-l_2{}^2+h^2)+r_2\,(r_1{}^2-l_1{}^2)]\,x-r_2\,(r_1{}^2-l_1{}^2)\,h\\ +\{h\,x^2+[(r_1{}^2-l_1{}^2)-(r_2{}^2-l_2{}^2)-h^2]\,x-(r_1{}^2-l_1{}^2-2\,r_1\,r_2)\,h\}\,y\\ +\{-(r_1+r_2)\,x+(2\,r_1-r_2)\,h\}\,y^2-h\,y^3=0 \quad . \quad . \quad . \quad . \quad . \quad (41)\end{aligned}$$

In using equation (8) instead of (2) for calculating y,

$$h\,x^2+[r_1{}^2-l_2{}^2)-(r_2{}^2-l_2{}^2)-h^2]\,x-(r_1{}^2-l_1{}^2)\,h$$

has been neglected in connection with $2r_1r_2h$. That is, the fraction λ has been neglected in comparison with unity, where

$$\lambda=\frac{h\,x^2+[(r_1{}^2-l_1{}^2)-(r_2{}^2-l_2{}^2)-h^2]\,x-(r_1{}^2-l_1{}^2)\,h}{2\,r_1\,r_2\,h} \quad . \quad (42)$$

If y_1 be the approximate value of y determined from equation (8), and y_2 be the value determined from (2),

$$y_1=(1+\lambda)\,y_2.$$

Similarly, if V_1 be the approximate value of V determined from (25), a closer approximation V_2 is given by the equation

$$V_1=(1+\lambda)\,V_2 \quad . \quad . \quad . \quad . \quad . \quad (43)$$

When y is a maximum or minimum (with the preceding restrictions as to the magnitude of V) x will not differ greatly from the value previously found, viz., $\left(m\pm\frac{n}{\sqrt{3}}\right)r_1$. Substituting this

value of x, and for h, l_1 and l_2, their values from (17), (18), and (19); (42) becomes

$$\lambda = \frac{1}{9}\left\{\frac{-(2\,\mathrm{R}+1)^2}{\mathrm{R}^2}\,m^2 \mp \frac{2\,(\mathrm{R}-1)\,(2\,\mathrm{R}+1)}{\sqrt{3}\,\mathrm{R}^2}\,m\,n + \frac{(\mathrm{R}^2+4\,\mathrm{R}+1)}{\mathrm{R}^2}\,n^2 \pm \frac{(\mathrm{R}-1)\,(\mathrm{R}+2)}{\sqrt{3}\,\mathrm{R}^2}\cdot\frac{n^2}{m}\right\} . \quad (44)$$

For given values of R and m, λ will in general vary with n, the correction for V being largest for the cases tabulated at the top of the columns. Taking the first cases given in Table III under $\mathrm{R}=1$ and $\mathrm{R}=\infty$, the values of λ are $-0{\cdot}078$ and $(-0{\cdot}031 \pm 0{\cdot}027)$; the values of V_2 are $1{\cdot}08\mathrm{V}_1$ and $1{\cdot}06\mathrm{V}_1$ respectively. These corrections for V are large enough to make it desirable—regarding the subject as a purely mathematical investigation—to determine V from the exact equation (41) instead of from the approximate equation (8). From the point of view of engineering construction, however, if V is so small as to be admissible, an increase of velocity-ratio variation to even $1{\cdot}08\mathrm{V}$ will have but slight influence on the smooth working of the pair of wheels.

Thus the tabulated values of V, though sometimes incorrect in the last figure, are sufficiently correct to guide the designer in judging whether a certain pair of wheels with circular teeth will approximate closely enough to constant velocity-ratio.

The error due to neglecting y^2 and y^3 in (41) may be investigated as above; but the following rougher approximation will be sufficient to show that this error is small. From inspection of Tables I to III, it will be seen that in the cases tabulated $(r_1^2 - l_1^2)$ and $(r_2^2 - l_2^2)$ are small in comparison with r_1^2 and r_2^2 respectively. The terms involving y in (41) may therefore be written—

$$(h\,x^2 - h^2 x + 2\,h\,r_1\,r_2)\,y + \{-(r_1+r_2)\,x + h\,(2\,r_1 - r_2)\}\,y^2 - h\,y^3$$

The ratio of the first term neglected to the term containing y is—

$$\left.\begin{aligned}\frac{-(r_1+r_2)\,x + h\,(2\,r_1 - r_2)}{h\,x^2 - h^2 x + 2\,h\,r_1\,r_2}\,y &= -\frac{(\mathrm{R}+1)\frac{x}{h} + (\mathrm{R}-2)}{\left(\frac{x}{r_1}\right)^2 - \frac{h}{r_1}\cdot\frac{x}{r^1} + 2\,\mathrm{R}}\cdot\frac{y}{r_1} \\ &= \frac{(\mathrm{R}+1)\frac{x}{h} + \mathrm{R} - 2}{2\,\mathrm{R} - \frac{x\,(h-x)}{r_1^2}}\cdot\frac{y}{r_1}\end{aligned}\right\} . \quad (45)$$

Now, $\frac{x}{h}$ is usually less than unity, but occasionally exceeds it (see *Fig. 10*). If $\frac{x}{h}$ be taken equal to 1, the numerator of the fraction (45) is $(2\,\mathrm{R}-1)\,y$; while if $\frac{x}{h}$ be less than 1, the numerator is less than $(2\,\mathrm{R}-1)\,y$. $\frac{x(h-x)}{{r_1}^2}$ is always less than 1; and therefore the denominator of the fraction (45) is always greater than $(2\,\mathrm{R}-1)\,r_1$. The fraction (45) is therefore generally less than $\frac{(2\,\mathrm{R}-1)\,y}{(2\,\mathrm{R}-1)\,r_1}$ or $\frac{y}{r_1}$. Now, from (24) and (25)

$$\frac{y_{\max}}{r_1} = \frac{\mathrm{V\,R}}{100\,(\mathrm{R}+1)} \quad . \quad . \quad . \quad . \quad (46)$$

and therefore, with external gear, when V = 4 per cent., $\frac{y}{r_1}$ can never be greater than 0·04. Thus, if V be the variation of the velocity-ratio determined by neglecting y^2 and y^3, the more exact value cannot with external gear be greater than 1·04 V. The error due to neglecting y^2 and y^3 may therefore be neglected.

Graph of $\frac{l_1}{r_1}$, $\frac{l_2}{r_2}$ and $\frac{h}{r_1}$. The calculations of Tables I–IV have been made by the use of Fuller's slide-rule, and it is hoped that the last figure is correct within one unit. A check has been obtained by drawing, for a number of cases taken at equal intervals in the Tables, the equivalent four-link mechanism in its three positions of zero variation from the assigned velocity-ratio. The values of $\frac{h}{r_1}$, $\frac{l_1}{r_1}$, and $\frac{l_2}{r_2}$ for any given values of R and n not tabulated may be found by interpolation, or by drawing a diagram showing graphically the variation of these quantities. Such a diagram for $m = 0{\cdot}2$ is shown in *Fig. 24*. The reciprocals of R are set off as abscissæ, the corresponding values of $\frac{l_1}{r_1}$, &c., as ordinates, a curve being obtained for each value of n. Zero abscissa corresponds to a rack, positive and negative abscissæ to external and internal gearing respectively. The full lines show the values of $\frac{l_1}{r_1}$, the dotted lines the values of $\frac{l_2}{r_2}$, and the thick curve the values of $\frac{h}{r_1}$. From this diagram it is easy to read off the values of $\frac{h}{r_1}$, $\frac{l_1}{r_1}$, and $\frac{l_2}{r_2}$ for any

given values of R and n. It may be noted here that the Tables are more compact and convenient when $m = \frac{p}{r_1}$ is taken in reference

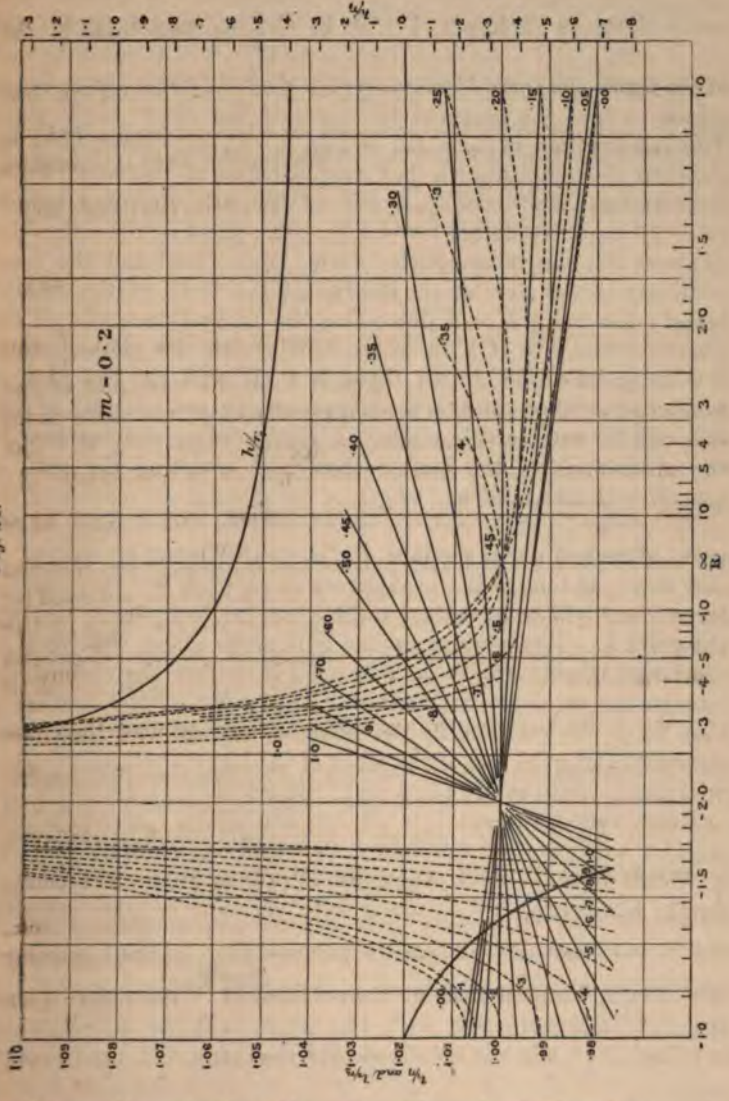


Fig. 24.

to the smaller wheel of the pair; throughout the Paper r_1 is therefore considered less than or equal to r_2.

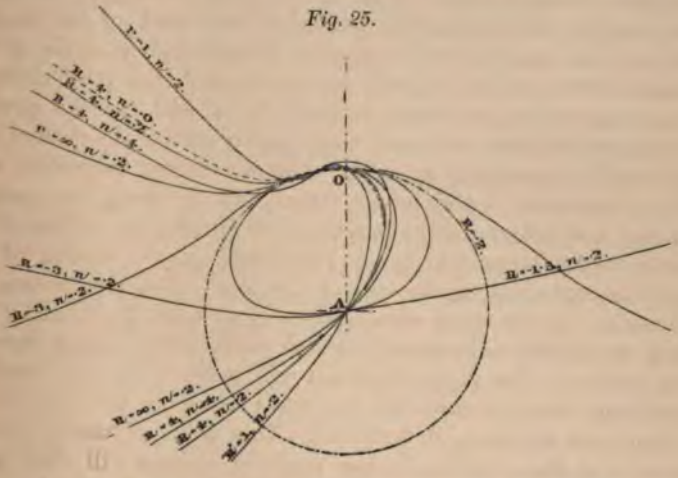
Path of Contact.—The length of the circular arc actually used for the tooth-outline is, in general, determined by drawing through l_1 and l_3 (the extreme positions of the point L on the equivalent link) circles concentric with the pitch-circles of the wheels. The outer circle on each wheel will be the addendum circle; the inner circle will determine the boundary of the rubbing part of the teeth, the space between it and the root circle being determined so that the points of the teeth of the other wheel clear. This construction is indicated in *Fig. 9*. In some cases, however, the path of contact is such that a modification of this construction is necessary. For example, in *Fig. 12* the path of contact is indicated by the thick dotted line $l_1 l_2 l_3$. The point l_1 will determine as above the addendum circle of the large wheel and the inner boundary of the circular-arc outline of the teeth of the smaller wheel; the point l_3 will determine the addendum circle of the smaller wheel, but if a circle concentric with the pitch-circle of the larger-wheel be drawn through l_3, it will cut the path of contact at another point, and consequently part of the path of contact will lie outside this circle. A circle drawn concentric with the pitch-circle of the larger wheel and touching the path of contact will determine the length of the circular arc outline of the teeth of the larger wheel. A peculiarity in the motion of the point of contact along the face of the tooth should be noticed in this case. If the small wheel drives clock-wise, the teeth of the large wheel will have contact at their points when passing through the point l_1. The point of contact will move along the teeth of the larger wheel towards the root until it reaches the end of the circular arc as above determined. This point of the tooth will then be at the position l^1, the point of contact will then move outwards along the face of the tooth of the large wheel, and contact will finally cease at the point which passes through l_3.

Exact Velocity Curves.—In *Fig. 25* are drawn polar curves of angular velocities of equivalent four-link mechanisms of pairs of wheels from Table I, Appendix IV, ($m = 0{\cdot}2$). The smaller crank A M is supposed to rotate with constant angular velocity, and in each case the assigned velocity-ratio $\frac{1}{R}$ of the large crank B N, *Fig. 1*, is represented by the radius A O. When the equivalent link M N is in line with the crank B N, the velocity-ratio is infinite, and when it is in line with the crank A M, the velocity-ratio is zero. When $R = -2$, the variation of velocity-ratio is zero, and the polar curve is the circle of radius A O, *Fig. 25*. For any other value of R the crank A M oscillates; the velocity curves

corresponding to the oscillation in one direction only have been drawn. The intercept on any radius between any curve and the circle of radius A O is, for small values, approximately proportional to the corresponding velocity-ratio variation. For the extreme case R = 4 and $n = 4$, the two maximum intercepts are perceptibly unequal, corresponding with the two values of λ (44). In the other cases the maximum intercepts are sensibly equal.

When A M is near the extreme left position of its swing (*Fig. 25*), if the assigned velocity-ratio of the given pair of wheels lie between -1 and -2, the actual value of the velocity-ratio is very great, and is of different sign from R; while if the assigned velocity-ratio lie between -2 and $-\infty$, or $+1$ and $+\infty$, the

Fig. 25.



actual value of the velocity-ratio is very great, and is of the same sign as R. A consideration of these curves will show that circular teeth are quite clear of each other when their respective centres M or N are outside the limits m_1 m_3 or n_1 n_3. Thus, suppose in a pair of wheels with external contact only one tooth is left on each wheel, and the smaller wheel drives in clockwise direction with constant velocity; if the circular teeth are in contact before the centre M moves up to position m_1 the velocity of the large wheel must be greater than $\frac{1}{R}$ times that of the small wheel. But in the actual wheel during this part of the motion, the velocity-ratio is not sensibly different from R, and the two teeth are in contact at the point m_1. The teeth of the large wheel must therefore have

travelled a smaller distance than in the former case, and must have been clear of the teeth of the small wheel before the centre M came up to the position m_1. Similarly, when the centre M moves beyond the position m_3, the circular teeth of the large wheel can be shown to move away from those of the small wheel. When R lies between -1 and -2, h is negative, and the teeth of the large wheel are concave, so that the same considerations show that in this case also circular wheel-teeth are quite clear of each other when the centre M is outside the limits m_1 m_3; also that roller-and-pin wheels clear when the rollers are outside the defined range of action. For example, in *Fig. 17*, though theoretically there is only one pair of rollers in contact, the drawing shows seven pairs of rollers apparently in contact at the same time. Taking into account the elasticity of the material in this example, it is probable that three or four pairs of rollers may be in contact, but the mutual pressure on the pair theoretically in contact will be greater than on the neighbouring pairs; thus the pressure on any pair of rollers will gradually increase from zero to a maximum when the equivalent link is in the position $m_2 n_2$, and will then gradually diminish.

For a pair of wheels with two or more pairs of teeth nominally in contact, the best method will probably be to design the equivalent four-link mechanism as if the arc of contact were equal to the pitch, and to determine the addendum circles so that the required number of pairs of teeth may be nominally in contact. Thus, in *Fig. 7*, by merely lengthening the teeth, that is, by making the addendum circles of larger and the root-circles of smaller radius, two pairs of teeth may be nominally in contact. With this arrangement, the pressure on the teeth will be greatest when the point of contact is near the pitch point; the work lost in friction will therefore be less than if the pressure remained constant during contact.

Effect of varying the distance between the wheel-centres.—If the distance between the centres of any pair of wheels be increased or diminished, the effect is to increase or diminish r_1 and r_2—R, l_1 and l_2 remaining constant. The values of $\frac{l_1}{r_1}$ and $\frac{l_2}{r_2}$ are therefore increased as the centres are brought nearer, and decreased as the centres are moved apart; the rate of variation of $\frac{l_1}{r_1}$ and $\frac{l_2}{r_2}$ being numerically the same, for small movements, as that of the distance between the centres. For example, if a pair of wheels (R = 4, $m = 0{\cdot}4$, $n = 0{\cdot}2$, and N = 16) be designed for a distance

of 50 inches between the shafts, and be erected with the distance 50·1 inches, the values of $\frac{l_1}{r_1}$ and $\frac{l_2}{r_2}$, intended to be 0·970 and 0·969 respectively (Table III), will be 0·968 and 0·967 (a diminution of 0·002), which numbers agree better with $n = 0{\cdot}15$ than $n = 0{\cdot}2$. Thus, if the teeth do not engage so deeply as was intended, n is reduced, and if the contact of a pair of teeth still takes place within the limits de, *Fig. 5*, V will also be reduced; if the teeth engage deeper than was intended, V is increased. In this respect therefore, circular teeth probably occupy a position intermediate between involute and cycloidal teeth.

The Paper is accompanied by drawings from which the *Figs.* in the text have been prepared.

APPENDIXES.

APPENDIX I.

ELIMINATION of $\sin\theta$ and $\cos\theta$ from—

$$(x - r_1\cos\theta)^2 + (y - r_1\sin\theta)^2 = l_1^2 \quad . \quad . \quad . \quad . \quad . \quad (1)$$
$$(x + r_2\cos\theta - h)^2 + (y + r_2\sin\theta)^2 = l_2^2 \quad . \quad . \quad . \quad . \quad (2)$$
$$\sin^2\theta + \cos^2\theta = 1 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Writing (1) and (2) in the form

$$2r_1 x\cos\theta + 2r_1 y\sin\theta + (l_1^2 - r_1^2 - r^2) = 0,$$
$$2r_2(x-h)\cos\theta + 2r_2 y\sin\theta + (-l_2^2 + r_2^2 + r^2 - 2hx + h^2) = 0,$$

where $r^2 = x^2 + y^2$, and solving for $\cos\theta$ and $\sin\theta$,

$$\cos\theta = \frac{y\{r_1(r_2^2 - l_2^2 + r^2 + h^2 - 2hx) + r_2(r_1^2 - l_1^2 + r^2)\}}{2r_1 r_2 hy},$$

$$\sin\theta = \frac{x\{r_1(r_2^2 - l_2^2 + r^2 + h^2 - 2hx) + r_2(r_1^2 - l_1^2 + r^2)\} - r_2 h(r_1^2 - l_1^2 + r^2)}{2r_1 r_2 hy}$$

Substituting these values in (3),

$$r^2\{\ \}^2 - 2r_2 hx(r_1^2 - l_1^2 + r^2)\{\ \} + r_2^2 h^2(r_1^2 - l_1^2 + r^2)^2 = (2r_1 r_2 hy)^2. \quad (4)$$

The expressions between the brackets { } being the same as occur in the expressions for $\sin\theta$ and $\cos\theta$.

If y is small, r is approximately equal to x; and writing $r = x$ in (4) it becomes

$$[x\{r_1(r_2^2 - l_2^2 + x^2 + h^2 - 2hx) - r_2(r_1^2 - l_1^2 + x^2)\} - r_2 h(r_1^2 - l_1^2 + x^2)]^2 = (2r_1 r_2 hy)^2,$$

i.e.,

$$[(r_1 + r_2)x^3 - h(2r_1 + r_2)x^2 + \{r_1(r_2^2 - l_2^2 + h^2) + r_2(r_2^2 - l_1^2)\}x - r_2 h(r_1^2 - l_1^2)]^2 = (2r_1 r_2 hy)^2.$$

APPENDIX II.

To find h, l_1^2, and l_2^2 from

$$3p(r_1 + r_2) = h(2r_1 + r_2) \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$
$$(3p^2 - q^2)(r_1 + r_2) = r_1(r_2^2 - l_2^2 + h^2) + r_2(r_1^2 - l_1^2) \quad . \quad . \quad (2)$$
$$(p^2 - q^2 p)(r_1 + r_2) = hr_2(r_1^2 - l_1^2) \quad . \quad . \quad . \quad . \quad . \quad (3)$$

From (1)
$$h = \frac{3p(r_1 + r_2)}{(2r_1 + r_2)} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

From (3)
$$l_1^2 = r_1^2 - \frac{p(p^2 - q^2)(r_1 + r_2)}{hr_2} = r_1^2 - \frac{(p^2 - q^2)(2r_1 + r_2)}{3r_2} \quad . \quad (5)$$

From (2)
$$\left.\begin{aligned} l_2^2 &= r_2^2 + h_2 + \frac{r_2(r_1^2 - l_1^2)}{r_1} - \frac{(3p^2 - q^2)(r_1 + r_2)}{r_1} \\ &= r_2^2 + \frac{9p^2(r_1 + r_2)^2}{(2r_1 + r_2)^2} + \frac{(p^2 - q^2)(2r_1 + r_2)}{3r_1} - \frac{(3p^2 - q^2)(r_1 + r_2)}{r_1} \\ &= r_2^2 - \frac{(r_1 + 2r_2)^2 p^2}{3r_1(2r_1 + r_2)^2} + \frac{(r_1 + 2r_2)q^2}{3r_1} \quad . \quad . \quad . \quad . \end{aligned}\right\} \quad (6)$$

APPENDIX III.

To find the maximum and minimum values of y when

$$b_2 y = a_0 x^3 + a_1 x^2 + a_2 x + a_3 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

The maximum and minimum values of y satisfy the equation $\frac{dy}{dx} = 0$. Therefore the values of x corresponding to the maximum and minimum values of y are given by the equation

$$3 a_0 x^2 + 2 a_1 x + a_2 = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Hence

$$x = \frac{-a_1 \pm (a_1^2 - 3 a_0 a_2)^{\frac{1}{2}}}{3 a_0} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Substituting from (3) in (1),

$$b_2 y = \frac{-a_1^3 \pm 3 a_1^2 (a_1^2 - 3 a_0 a_2)^{\frac{1}{2}} - 3 a_1 (a_1^2 - 3 a_0 a_2) \pm (a_1^2 - 3 a_0 a_2)^{\frac{3}{2}}}{27 a_0^2}$$

$$+ \frac{a_1 \{a_1^2 \mp 2 a_1 (a_1^2 - 3 a_0 a_2)^{\frac{1}{2}} + a_1^2 - 3 a_0 a_2\}}{9 a_0^2} + \frac{a_2 \{-a_1 \pm (a_1^2 - 3 a_0 a_2)^{\frac{1}{2}}\}}{3 a_0} + a_3$$

$$= \frac{1}{9 a_0} \left\{ \frac{2 a_1^3}{3 a_0} + 9 a_0 a_3 - 3 a_1 a_2 \right\} \pm \frac{2 (a_1^2 - 3 a_0 a_2)^{\frac{3}{2}}}{27 a_0^2}$$

i.e.,

$$y \begin{matrix} \text{max.} \\ \text{min.} \end{matrix} = \frac{1}{9 a_0 b_2} \left\{ \frac{2 a_1^3}{3 a_0} + 9 a_0 a_3 - 3 a_1 a_2 \right\} \pm \frac{2 (a_1^2 - 3 a_0 a_2)^{\frac{3}{2}}}{27 a_0^2 b_2} \quad . \quad . \quad (4)$$

APPE

TABLE I.-

R		1·0			1·5			2·0			3·0			
$\frac{h}{r_1}$		0·400			0·429			0·450			0·480			
n	N, Approximate Number of Teeth in Small Wheel.	$\frac{l}{r}$	V	Maximum Obliquity.	$\frac{l_1}{r_1}$	$\frac{l_2}{r_2}$	V	$\frac{l_1}{r_1}$	$\frac{l_2}{r_2}$	V	$\frac{l_1}{r_1}$	$\frac{l_2}{r_2}$	V	Maximum Obliquity
			Per Cent.	Degrees.			Per Cent.			Per Cent.			Per Cent.	Degrees.
0·50	6·3	..	..	..	..	..	..	..	..	..	..	..	..	..
0·45	7·0	..	..	..	..	..	..	..	..	..	..	..	..	..
0·40	7·9	..	..	..	..	..	..	..	..	..	..	..	..	..
0·35	9·0	..	..	..	..	..	..	..	..	..	1·023	1·006	3·1	13·4
0·30	10	..	..	..	1·019	1·011	3·4	1·017	1·006	2·6	1·014	1·001	1·9	12·7
0·25	13	1·011	3·0	11·4	1·009	1·003	1·9	1·007	1·000	1·5	1·006	0·998	1·1	12·1
0·20	16	1·000	1·5	11·4	1·000	0·996	1·0	1·000	0·995	0·77	1·000	0·995	0·57	11·4
0·15	20	0·991	0·63	11·4	0·993	0·991	0·41	0·994	0·992	0·32	0·995	0·993	0·23	10·7
0·10	31	0·985	0·19	11·4	0·988	0·987	0·12	0·990	0·989	0·10	0·992	0·991	0·07	10·0
0·05	63	0·981	0·02	11·4	0·985	0·985	0·01	0·988	0·987	0·01	0·990	0·990	0·01	9·4
0·00	∞	0·980	0·00	11·4	0·984	0·984	0·00	0·987	0·987	0·00	0·989	0·990	0·00	8·8

DIX IV.

$m = 0{\cdot}20$.

4·0			5·0			10·0				∞		
0·500			0·514			0·550				0·600		
$\frac{l_1}{r_1}$	$\frac{l_2}{r_2}$	V	$\frac{l_1}{r_1}$	$\frac{l_2}{r_2}$	V	$\frac{l_1}{r_1}$	$\frac{l_2}{r_2}$	V	Maximum Obliquity.	$\frac{l_1}{r_1}$	$\frac{(r_2 - l_2)}{r_1}$	V
..	..	Per Cent. ..	..	..	Per Cent. ..	..	..	Per Cent. ..	Degrees. ..	1·034	−0·030	Per Cent. 4·0
..	..	..	..	..	..	1·032	1·003	3·8	15·9	1·027	−0·014	2·9
1·030	1·006	3·8	1·028	1·004	3·4	1·024	1·001	2·7	15·0	1·020	0·000	2·1
1·020	1·003	2·6	1·019	1·002	2·3	1·016	1·000	1·8	14·1	1·014	0·012	1·4
1·012	1·000	1·6	1·012	0·999	1·5	1·010	0·999	1·1	13·2	1·008	0·023	0·87
1·006	0·997	0·94	1·005	0·997	0·84	1·004	0·998	0·66	12·3	1·004	0·032	0·50
1·000	0·995	0·48	1·000	0·996	0·43	1·000	0·997	0·34	11·4	1·000	0·040	0·26
0·996	0·994	0·20	0·996	0·994	0·18	0·996	0·996	0·14	10·6	0·997	0·046	0·11
0·992	0·993	0·06	0·993	0·993	0·05	0·994	0·996	0·04	9·7	0·995	0·050	0·03
0·991	0·992	0·01	0·991	0·993	0·01	0·992	0·996	0·00	8·9	0·994	0·052	0·0
0·990	0·991	0·00	0·991	0·993	0·00	0·992	0·996	0·00	8·0	0·993	0·053	0·0

TABLE Ib.—INTERNAL

R		10·0			5·0		
$\frac{h}{r_1}$		0·675			0·800		
n	N, Approximate Number of Teeth in Small Wheel.	$\frac{l_1}{r_1}$	$\frac{l_2}{r_2}$	V	$\frac{l_1}{r_1}$	$\frac{l_2}{r_2}$	V
				Per Cent.			Per Cent.
1·00	3·1	..	..	..	..	..	..
0·90	3·5	..	..	..	..	..	..
0·80	3·9	..	..	..	..	..	..
0·70	4·5	..	..	..	..	..	..
0·60	5·0	..	..	..	1·032	1·000	3·3
0·50	6·3	1·028	0·999	2·9	1·021	1·006	1·9
0·45	7·0	1·022	1·001	2·1	1·016	1·009	1·4
0·40	7·9	1·016	1·002	1·5	1·012	1·012	1·0
0·35	9·0	1·011	1·003	1·0	1·008	1·014	0·66
0·30	10	1·007	1·004	0·62	1·005	1·016	0·42
0·25	13	1·003	1·005	0·36	1·002	1·018	0·24
0·20	16	1·000	1·006	0·18	1·000	1·019	0·12
0·15	20	0·998	1·006	0·08	0·998	1·020	0·05
0·10	31	0·996	1·007	0·02	0·997	1·021	0·01
0·05	63	0·995	1·007	0·00	0·996	1·021	0·00
0·00	∞	0·995	1·007	0·00	0·996	1·022	0·00

GEAR.—$m = 0{\cdot}20$.

4·0			3·0			2·0	1·5		
0·900			1·200			∞	− 0·600		
$\frac{l_1}{r_1}$	$\frac{l_2}{r_2}$	V	$\frac{l_1}{r_1}$	$\frac{l_2}{r_2}$	V	—	$\frac{l_1}{r_1}$	$\frac{l_2}{r_2}$	V
..	..	Per Cent. ..	..	..	Per Cent. ..		0·945	0·945	Per Cent. 3·6
..	..	..	..	..	..		0·956	0·975	2·6
..	..	..	1·033	1·033	3·6		0·966	1·000	1·8
..	..	..	1·025	1·046	2·4		0·975	1·022	1·2
1·027	1·009	2·6	1·018	1·057	1·5		0·982	1·041	0·77
1·017	1·017	1·5	1·012	1·067	0·89	V = 0·000.	0·988	1·056	0·45
1·013	1·021	1·1	1·009	1·071	0·65		0·991	1·063	0·32
1·010	1·024	0·77	1·007	1·075	0·45	$\frac{l_2}{r_2} = \infty$,	0·993	1·069	0·23
1·007	1·027	0·52	1·005	1·078	0·30		0·995	1·074	0·15
1·004	1·029	0·32	1·003	1·081	0·19		0·997	1·078	0·10
1·002	1·031	0·19	1·001	1·083	0·11	$\frac{l_1}{r_1} = 1{\cdot}000$,	0·999	1·082	0·06
1·000	1·033	0·10	1·000	1·085	0·06		1·000	1·085	0·03
0·999	1·034	0·04	0·999	1·087	0·02		1·001	1·087	0·01
0·998	1·035	0·01	0·998	1·088	0·01		1·002	1·089	0·00
0·997	1·035	0·00	0·998	1·089	0·00		1·002	1·090	0·00
0·997	1·035	0·00	0·998	1·089	0·00		1·002	1·090	0·00

TABLE II.

R		1·0			1·5			2·0			3·0			
$\frac{h}{r_1}$		0·600			0·643			0·675			0·720			
n	N, Approximate Number of Teeth in Small Wheel.	$\frac{l_1}{r_1}$	V	Maximum Obliquity.	$\frac{l_1}{r_1}$	$\frac{l_2}{r_2}$	V	$\frac{l_1}{r_1}$	$\frac{l_2}{r_2}$	V	$\frac{l_1}{r_1}$	$\frac{l_2}{r_2}$	V	Maximum Obliquity.
			Per Cent.	Degrees.			Per Cent.			Per Cent.			Per Cent.	Degrees.
0·55	5·7	..	..	..	..	..	..	..	..	..	..	..	..	..
0·50	6·3	..	..	..	..	..	..	..	..	..	..	..	..	..
0·45	7·0	..	..	..	..	..	..	..	..	..	..	..	..	..
0·40	7·9	..	..	..	..	..	..	..	..	..	1·019	0·998	3·0	18·7
0·35	9·0	..	..	..	1·013	1·001	3·6	1·011	0·996	2·8	1·009	0·993	2·0	18·0
0·30	10	1·000	3·5	17·4	1·000	0·992	2·2	1·000	0·989	1·7	1·000	0·989	1·3	17·4
0·25	13	0·986	2·0	17·4	0·989	0·984	1·3	0·991	0·984	1·0	0·992	0·985	0·74	16·7
0·20	16	0·975	1·0	17·4	0·980	0·977	0·66	0·983	0·979	0·51	0·986	0·982	0·38	16·0
0·15	20	0·966	0·42	17·4	0·974	0·971	0·27	0·977	0·975	0·21	0·981	0·980	0·16	15·4
0·10	31	0·960	0·13	17·4	0·969	0·968	0·08	0·973	0·972	0·06	0·978	0·978	0·05	14·8
0·05	63	0·956	0·01	17·4	0·965	0·965	0·01	0·971	0·971	0·01	0·976	0·977	0·00	14·1
0·00	∞	0·954	0·00	17·4	0·964	0·965	0·00	0·970	0·970	0·00	0·975	0·977	0·00	13·4

TABLE III.—

R		1·0			1·5			2·0			3·0			
$\frac{h}{r_1}$		0·800			0·857			0·900			0·960			
n	N, Approximate Number of Teeth in Small Wheel.	$\frac{l_1}{r_1}$	V	Maximum Obliquity.	$\frac{l_1}{r_1}$	$\frac{l_2}{r_2}$	V	$\frac{l_1}{r_1}$	$\frac{l_2}{r_2}$	V	$\frac{l_1}{r_1}$	$\frac{l_2}{r_2}$	V	Maximum Obliquity.
			Per Cent.	Degrees.			Per Cent			Per Cent.			Per Cent.	Degrees.
0·60	5·0	..	..	..	..	..	..	..	..	..	..	..	..	..
0·55	5·7	..	..	..	..	..	..	..	..	..	..	..	..	..
0·50	6·3	..	..	..	..	..	..	..	..	..	..	..	..	..
0·45	7·0	..	..	..	..	..	..	..	..	..	1·012	0·986	3·3	24·3
0·40	7·9	..	..	..	1·000	0·985	4·0	1·000	0·981	3·1	1·000	0·980	2·3	23·6
0·35	9·0	0·981	4·1	23·6	0·985	0·974	2·7	0·987	0·973	2·1	0·989	0·975	1·5	22·9
0·30	10	0·964	2·6	23·6	0·972	0·964	1·7	0·977	0·966	1·3	0·980	0·971	0·96	22·2
0·25	13	0·950	1·5	23·6	0·961	0·956	0·97	0·967	0·960	0·75	0·973	0·967	0·56	21·5
0·20	16	0·938	0·77	23·6	0·952	0·949	0·50	0·959	0·955	0·38	0·966	0·964	0·28	20·8
0·15	20	0·928	0·32	23·6	0·945	0·943	0·30	0·953	0·951	0·16	0·961	0·962	0·12	20·1
0·10	31	0·922	0·10	23·6	0·940	0·939	0·06	0·949	0·949	0·05	0·957	0·961	0·04	19·4
0·05	63	0·918	0·01	23·6	0·937	0·937	0·00	0·946	0·947	0·00	0·955	0·960	0·00	18·7
0·00	∞	0·917	0·00	23·6	0·936	0·936	0·00	0·945	0·947	0·00	0·955	0·959	0·00	18·0

$m = 0{\cdot}30$.

4·0			5·0			10·0				∞		
0·750			0·771			0·825				0·900		
$\frac{l_1}{r_1}$	$\frac{l_2}{r_2}$	V	$\frac{l_1}{r_1}$	$\frac{l_2}{r_2}$	V	$\frac{l_1}{r_1}$	$\frac{l_2}{r_2}$	V	Maximum Obliquity.	$\frac{l_1}{r_1}$	$\frac{(r_2 - l_2)}{r_1}$	V
		Per Cent.			Per Cent.			Per Cent.	Degrees.			Per Cent.
..	..	..	..	..	..	..	..	..	..	1·035	0·019	3·6
..	..	..	..	..	..	1·032	0·999	3·5	21·0	1·026	0·037	2·7
1·028	1·000	3·6	1·026	0·999	3·3	1·022	0·997	2·6	20·1	1·019	0·052	1·9
1·017	0·996	2·6	1·016	0·995	2·3	1·014	0·996	1·8	19·2	1·012	0·067	1·4
1·008	0·992	1·7	1·008	0·993	1·5	1·006	0·995	1·2	18·3	1·005	0·079	0·92
1·000	0·989	1·1	1·000	0·990	0·97	1·000	0·994	0·76	17·4	1·000	0·090	0·58
0·993	0·987	0·62	0·994	0·988	0·56	0·994	0·993	0·44	16·5	0·995	0·099	0·33
0·987	0·985	0·32	0·988	0·987	0·29	0·990	0·992	0·23	15·6	0·992	0·107	0·17
0·983	0·983	0·13	0·984	0·985	0·12	0·987	0·991	0·09	14·7	0·989	0·112	0·07
0·980	0·982	0·04	0·981	0·984	0·04	0·984	0·991	0·03	13·8	0·987	0·117	0·02
0·978	0·981	0·00	0·980	0·984	0·00	0·982	0·990	0·00	12·9	0·986	0·119	0·00
0·977	0·981	0·00	0·979	0·984	0·00	0·982	0·990	0·00	12·0	0·985	0·120	0·00

$m = 0{\cdot}40$.

4·0			5·0			10·0				∞		
1·000			1·029			1·100				1·200		
$\frac{l_1}{r_1}$	$\frac{l_2}{r_2}$	V	$\frac{l_1}{r_1}$	$\frac{l_2}{r_2}$	V	$\frac{l_1}{r_1}$	$\frac{l_2}{r_2}$	V	Maximum Obliquity.	$\frac{l_1}{r_1}$	$\frac{(r_2 - l_2)}{r_1}$	V
		Per Cent.			Per Cent.			Per Cent.	Degrees.			Per Cent.
..	..	..	..	..	..	..	..	..	..	1·033	0·093	3·5
..	..	..	1·033	0·993	3·7	1·028	0·994	3·5	26·5	1·023	0·112	2·7
1·022	0·989	3·8	1·021	0·989	2·8	1·018	0·992	2·6	25·5	1·015	0·128	2·0
1·010	0·985	2·7	1·010	0·986	2·0	1·008	0·990	1·9	24·6	1·007	0·146	1·5
1·000	0·981	1·9	1·000	0·983	1·4	1·000	0·988	1·4	23·6	1·000	0·160	1·0
0·991	0·977	1·3	0·991	0·980	0·97	0·993	0·987	0·91	22·6	0·994	0·172	0·69
0·982	0·974	0·81	0·984	0·977	0·61	0·986	0·986	0·57	21·6	0·988	0·183	0·43
0·975	0·971	0·47	0·977	0·975	0·35	0·980	0·985	0·33	20·7	0·984	0·192	0·25
0·970	0·969	0·25	0·972	0·974	0·18	0·976	0·984	0·17	19·8	0·980	0·200	0·13
0·965	0·968	0·10	0·968	0·972	0·07	0·972	0·984	0·07	18·9	0·977	0·206	0·05
0·962	0·966	0·03	0·965	0·971	0·02	0·970	0·983	0·02	18·0	0·975	0·210	0·02
0·960	0·966	0·00	0·963	0·971	0·00	0·968	0·983	0·00	17·1	0·974	0·212	0·00
0·959	0·965	0·00	0·962	0·971	0·00	0·967	0·983	0·00	16·2	0·973	0·213	0·00

TABLE IV.—ROLLER-

R		1·0		1·5			2·0		
N, Number of Teeth in one Step of Small Wheel.	$\frac{h}{r_1}$	$\frac{l_1}{r_1}$	V	$\frac{l_1}{r_1}$	$\frac{l_2}{r_2}$	V	$\frac{l_1}{r_1}$	$\frac{l_2}{r_2}$	V
			Per Cent.			Per Cent.			Per Cent.
									With one
7	0·448	..	..	..	..	..	..	..	..
8	0·393	..	..	..	..	..	..	..	..
9	0·349	..	..	..	..	..	..	..	..
10	0·314	..	..	..	..	..	..	..	..
11	0·286	..	..	..	..	..	1·022	1·012	3·5
12	0·262	..	..	1·020	1·013	3·7	1·018	1·010	3·0
13	0·242	..	..	1·017	1·011	3·1	1·016	1·008	2·5
14	0·224	1·018	3·9	1·015	1·010	2·7	1·013	1·007	2·2
15	0·209	1·016	3·4	1·013	1·009	2·3	1·012	1·006	1·9
20	0·157	1·009	1·9	1·007	1·005	1·3	1·007	1·004	1·1
25	0·126	1·006	1·2	1·004	1·003	0·84	1·004	1·002	0·68
30	0·105	1·004	0·84	1·003	1·002	0·58	1·003	1·002	0·47
									With two
3	1·047	..	..	..	..	..	..	..	..
4	0·785	..	..	..	..	..	1·011	0·992	3·3
5	0·628	1·000	3·8	1·005	0·996	2·6	1·007	0·995	2·1
6	0·524	1·000	2·6	1·003	0·997	1·8	1·005	0·997	1·5
8	0·393	1·000	1·5	1·002	0·998	1·0	1·003	0·998	0·83
10	0·314	1·000	0·95	1·001	0·999	0·66	1·002	0·999	0·53
20	0·157	1·000	0·24	1·000	1·000	0·16	1·000	1·000	0·13

AND-PIN WHEELS.

4·0			10·0			∞		
$\frac{l_1}{r_1}$	$\frac{l_2}{r_2}$	V	$\frac{l_1}{r_1}$	$\frac{l_2}{r_2}$	V	$\frac{l_1}{r_1}$	$\frac{r_2-l_2}{r_1}$	V
		Per Cent.			Per Cent.			Per Cent.
step ($k = 1$).								
..	..	..	..	..	..	1·030	−0·037	3·9
..	..	..	1·026	1·003	3·6	1·023	−0·029	3·0
1·025	1·007	3·7	1·021	1·002	2·8	1·018	−0·023	2·3
1·021	1·006	3·0	1·017	1·002	2·3	1·015	−0·018	1·9
1·017	1·005	2·5	1·014	1·002	1·9	1·012	−0·015	1·6
1·014	1·004	2·1	1·012	1·001	1·6	1·010	−0·013	1·3
1·012	1·004	1·8	1·010	1·001	1·4	1·009	−0·011	1·1
1·010	1·003	1·5	1·009	1·001	1·2	1·007	−0·009	0·97
1·009	1·003	1·3	1·008	1·001	1·0	1·006	−0·008	0·84
1·005	1·001	0·74	1·004	1·001	0·57	1·004	−0·005	0·47
1·003	1·001	0·47	1·003	1·000	0·37	1·002	−0·003	0·30
1·002	1·001	0·33	1·002	1·000	0·25	1·002	−0·002	0·21
steps ($k = 2$).								
..	..	..	1·025	0·994	3·2	1·025	0·071	2·6
1·014	0·994	2·3	1·014	0·997	1·8	1·014	0·040	1·5
1·009	0·996	1·5	1·009	0·998	1·1	1·009	0·026	0·95
1·006	0·997	1·1	1·006	0·998	0·80	1·006	0·018	0·66
1·003	0·998	0·58	1·004	0·999	0·45	1·003	0·010	0·37
1·002	0·999	0·37	1·002	0·999	0·29	1·002	0·006	0·24
1·001	1·000	0·09	1·001	1·000	0·07	1·001	0·002	0·06

TABLE IV*b*.—ROLLER-AND-PIN WHEELS. INTERNAL GEAR.

	R		10			4			2			1·5		
	N, Number of Teeth in One Step of Small Wheel.	$\frac{h}{r_1}$	$\frac{l_1}{r_1}$	$\frac{l_2}{r_2}$	V	$\frac{l_1}{r_1}$	$\frac{l_2}{r_2}$	V	$\frac{l_1}{r_1}$	$\frac{l_2}{r_2}$	V	$\frac{l_1}{r_1}$	$\frac{l_2}{r_2}$	V
					Per Cent.			Per Cent			Per Cent.			Per Cent.
With one step (k=1.)	4	0·785	..	..	..	..	..	..	1·000	1·000	3·0	0·969	1·069	1·3
	5	0·628	..	..	..	..	..	..	1·000	1·000	1·9	0·980	1·045	0·84
	6	0·524	..	..	..	1·022	0·992	3·0	1·000	1·000	1·3	0·986	1·031	0·59
	7	0·449	1·024	0·996	3·1	1·016	0·994	2·2	1·000	1·000	0·97	0·990	1·023	0·43
	8	0·393	1·019	0·997	2·4	1·012	0·996	1·7	1·000	1·000	0·74	0·992	1·018	0·33
	10	0·314	1·012	0·998	1·5	1·008	0·997	1·1	1·000	1·000	0·47	0·995	1·011	0·21
	15	0·209	1·006	0·999	0·72	1·003	0·999	0·48	1·000	1·000	0·21	0·998	1·005	0·09
	20	0·157	1·003	0·999	0·38	1·002	0·999	0·27	1·000	1·000	0·12	0·999	1·003	0·05
	30	0·105	1·001	1·000	0·18	1·001	1·000	0·12	1·000	1·000	0·05	0·999	1·001	0·02
With two steps (k=2.)	2	1·571	..	..	..	1·040	1·062	3·3	1·000	1·209	1·5	0·981	1·454	0·66
	3	1·047	1·023	1·009	2·1	1·018	1·028	1·5	1·000	1·098	0·66	0·991	1·223	0·29
	4	0·785	1·013	1·005	1·2	1·010	1·016	0·83	1·000	1·057	0·37	0·995	1·138	0·16
	5	0·628	1·008	1·003	0·77	1·006	1·010	0·53	1·000	1·037	0·24	0·997	1·085	0·10
	6	0·524	1·006	1·002	0·53	1·004	1·007	0·37	1·000	1·025	0·16	0·998	1·060	0·07
	8	0·393	1·003	1·001	0·30	1·003	1·004	0·21	1·000	1·014	0·09	0·999	1·034	0·04
	10	0·314	1·002	1·001	0·19	1·002	1·003	0·13	1·000	1·009	0·06	0·999	1·022	0·03
	15	0·209	1·001	1·000	0·09	1·001	1·001	0·06	1·000	1·004	0·03	1·000	1·010	0·01
	20	0·157	1·001	1·000	0·05	1·000	1·001	0·03	1·000	1·002	0·01	1·000	1·006	0·01

(Paper No. 2740.)

"On the Determination of the Thermal Conductivities of Heat-Insulators."

By Professor ANDREW JAMIESON, M. Inst. C.E.

THE investigation described in this Paper was undertaken for the purpose of determining the relative and absolute thermal conductivities of substances used as lagging for steam-boilers, for parts of steam-engines and for refrigerating-machines.

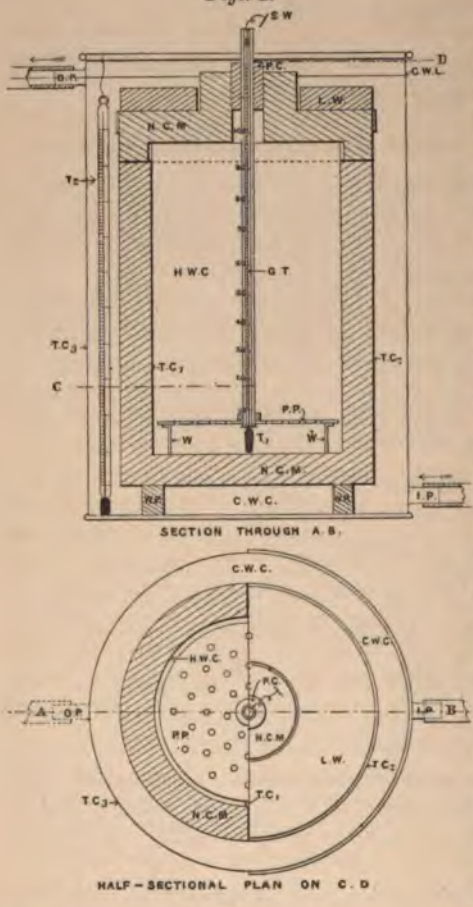
The method adopted was to observe the fall of temperature in a known weight of hot water contained in a vessel coated on all sides with a certain thickness of the material under examination, the outer surface of which was maintained at a constant temperature by the continuous flow of cold water through a water-jacket.

Description of the Apparatus.—The apparatus used in the tests consisted of three cylindrical tin cases, indicated in *Fig. 1* by T C_1, T C_2, T C_3. The first or innermost of the three, T C_1, was $9\frac{3}{4}$ inches high by 6 inches in diameter, and, when filled, held exactly 10 lbs. of fresh hot water. It was fitted with a watertight lid, having a central funnel, through which the hot water was supplied. The second vessel, T C_2, which contained the first, measured $11\frac{3}{4}$ inches in height by 8 inches in diameter. The non-conducting material, N C M, under test filled the space, of 1 inch in thickness, between the outside of the first and the inside of the second case. The third or outer vessel, T C_3, was $14\frac{1}{2}$ inches high by 10 inches in diameter. It formed the water-jacket for the first and second cylinders and the material under test between them.

A perforated piston, P P, fixed to a central glass tube, G T, which contained a tightly-fitted thermometer, T_1, was provided for stirring the water in the innermost vessel. Stops, W W, were attached to its under side to prevent the thermometer-bulb striking the bottom of this vessel. In order to permit of the introduction of the perforated piston into the inner tin case T C_1,

the latter was provided with a lid which was coated to a thickness of 1 inch with the same non-conducting material as the sides and bottom. The glass tube, G T, passed tightly through the centre of a paraffined wooden plug, P C, fitted into the neck of the lid. It was used as a handle to move the perforated piston whilst stirring the water in the hot-water chamber, H W C. The thermometer was raised and lowered in the tube by the string with wire check, S W. The cold-water chamber, C W C, or space between the second and outer vessels, also contained a thermometer, T_2, and was provided with inlet and outlet water-pipes, I P and O P. The water in this vessel was maintained at the level C W L. The second and inner vessels with their contents were supported in their position inside the outer vessel by four wooden pegs, W P. The circular lead weight, L W, was placed on the lid of the second vessel in order to prevent it and its contents from floating, and to keep the non-conducting material dry during a test. The lids of the inner and second vessels were cemented to their respective cases by means of Chatterton's compound.

Figs. 1.



In the appended list of the non-conducting materials tested, the index letters refer to those upon the curves, *Fig. 2*, and in the Table of results, p. 297.

B. Composition of fossil meal, roasted and mixed in Glasgow, consisting of 60 per cent. of washed white German kieselguhr and 40 per cent. of binding matter. It is applied in a wet state to steam-pipes or boilers, steam being kept up to dry the material quickly. It adheres well to the surfaces, making a neat covering.

C. Silicate cotton, or slag-wool, produced by blowing steam into melted blast-furnace slag.

D. Composition of kieselguhr[1] from mines in Germany, with 10 per cent. of binding material, viz., fibre and mucilaginous extract of several vegetable matters.

E. Cement consisting of fine blue clay mixed with flax, jute and woollen waste or cow-hair in equal proportions, surrounded by a layer of hair-felt and canvas.

F. Fibrous composition of fine blue clay from the Glasgow district, mixed with flax, hemp, rope, jute, cow-hair and woollen waste.

G. Papier maché composition consisting of paper-pulp mixed with clay and carbon, together with hair and fragments of hemp-rope.

H. A lighter modification of G.

Method of making the Tests.—A separate inner case was provided for each specimen of non-conducting material, with which it was covered to a uniform thickness of 1 inch in the manner in which it would be employed in practice. The non-conducting composition was applied in layers, carefully dried in succession, to ensure that the dryness necessary to the accuracy of the tests was obtained. Each covered tin case was tested as follows: Ten pounds of boiling water were poured through the funnel into the hot-water chamber. Cold water was then allowed to flow uniformly from the main water-pipe, and to circulate freely through the cold-water chamber. During no test

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[1] Average Analysis of the Kieselguhr used in preparing Sample D.

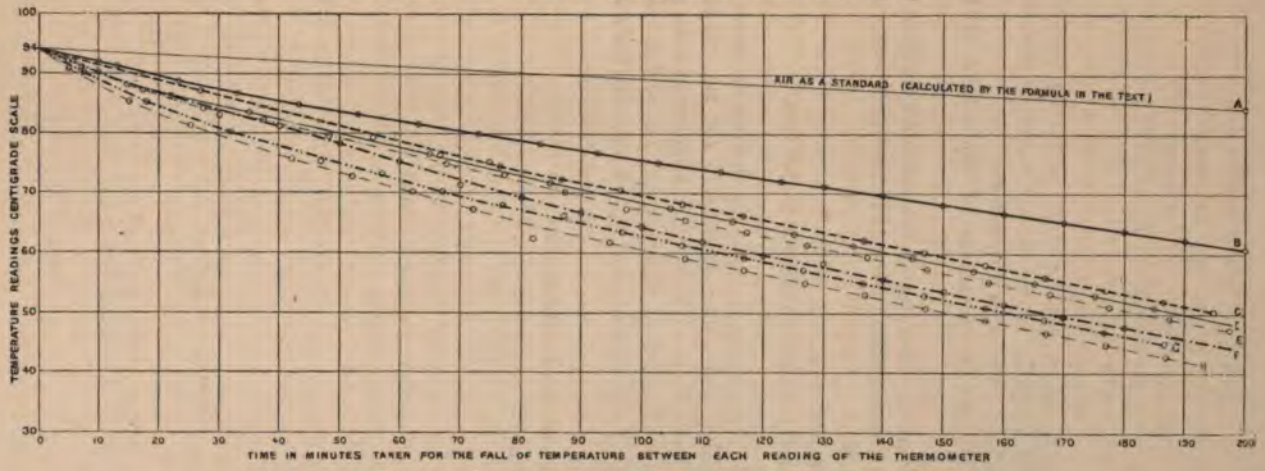
	Per cent.
Silica	83·8
Magnesia	0·7
Lime	0·8
Alumina	1·0
Peroxide of iron	2·1
Organic matter	4·5
Moisture and loss	7·1
	100·0

was the temperature in this chamber observed to rise as much as 1° C. The outer surface of the non-conductor was, therefore, kept at a constant temperature throughout each test. In order to prevent the temperature of the hot water from falling too quickly at first, and to bring the non-conductor and the whole apparatus to a condition of constant temperature or heat-equilibrium, steam at atmospheric pressure, generated in a florence-flask, was first passed into the inner vessel by means of a glass tube led into it through the funnel. The steam-pipe was then removed, and the paraffined cork fitted tightly into its position. The first reading was always taken when the temperature of the hot water had just fallen to 94° C. The water was stirred by the perforated piston prior to the readings of the thermometers in the two chambers, which were taken simultaneously, being noted. Successive readings of both thermometers were then taken in the same way, and recorded every ten minutes. These readings have been plotted as ordinates, with the time between each reading in minutes as abscissæ, *Fig. 2.* The curves show the gradual fall of temperature of the water in the inner chamber during the tests of each of the several substances experimented upon. Each experiment lasted about three hours, during which a fall in temperature through a good range was obtained. The loss of heat at the end of any fixed time therefore constitutes a measure of the conductivity of each substance. The results are given in Table I, which shows in each case the total fall of temperature in degrees Centigrade after an interval of two hours from the commencement of the test.

The higher the specific gravity of the composition under test the greater will be the quantity of heat which it draws from the boiling water in the hot-water chamber, at the beginning of the test, to bring it and the apparatus to a condition of heat-equilibrium. The curves fall very quickly at first, thus indicating the rapid abstraction of heat at the start; but as soon as the compositions and the apparatus became heated throughout their mass, the fall of temperature was more regular, and the curves, therefore, fall away more gradually. While, therefore, the beginning of a curve may show for one material a greater conductivity than that of a material of a smaller density, the subsequent portions of the curves may show the reverse. The readings from which the absolute thermal conductivities of the different substances are calculated were chosen from the uniform portions of the curves, and, consequently, the rapid fall near the starting-point has no effect on the results.

Fig. 2.

CURVES SHOWING FALL OF TEMPERATURE DURING THE TESTS.



REFERENCE LETTERS TO CURVES. (See also list of materials, p. 293.)

A. Dry air.
B. Fossil meal composition.
C. Silicate cotton composition.
D. Kieselguhr composition.
E. Cement with hair-felt.
F. Fibrous composition.
G. Papier maché composition (*a*).
H. " " " (*b*).

l conductivities were calculated from the formula[1]

$$K = \frac{m\,x}{A} \cdot \frac{\log_e \frac{\tau_1 - \tau_0}{\tau_2 - \tau_0}}{t_2 - t_1},$$

where,

m is the mass of the water together with the products of the masses and specific heats of all other bodies within the covering of the substance under test;

τ, τ_1, τ_2, τ_3, &c., the temperatures of the water in the inside case;

τ_0 the temperature of the water in the outside case (constant); and

t_1, t_2, t_3 &c., the times of observation of the temperatures τ_1, τ_2, τ_3, &c.,

A the mean area,

x the thickness, and

K the conductivity, of the substance under test.

The curve for air in *Fig. 2* is obtained directly from the above formula, in which the value 0·0000558 for its conductivity is substituted. The effects of the small uncovered area at the top of the hot-water chamber of the mass of the perforated piston or stirrer, with the thermometer, and of the corners, were neglected.

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[1] **This formula is obtained as follows:—**

From the definition of quantity of heat—

$$Q = m\,(\tau - \tau_0);$$

$$\therefore \quad dQ = -\,m\,d\,(\tau - \tau_0).$$

Again, from the formula for the flow of heat—

$$\frac{dQ}{dt} = \frac{K\,A}{x}\,(\tau - \tau_0);$$

$$\therefore \quad dt = -\,\frac{m\,x}{K\,A} \cdot \frac{d\,(\tau - \tau_0)}{\tau - \tau_0};$$

and thus—

$$t_1 - t_2 = -\,\frac{m\,x}{K\,A} \int_{(\tau_1 - \tau_0)}^{(\tau_2 - \tau_0)} \frac{d\,(\tau - \tau_0)}{(\tau - \tau_0)};$$

$$\therefore \quad t_2 - t_1 = \frac{m\,x}{K\,A} \log_e \frac{\tau_1 - \tau_0}{\tau_2 - \tau_0};$$

or—

$$K = \frac{m\,x}{A} \cdot \frac{\log_e \frac{\tau_1 - \tau_0}{\tau_2 - \tau_0}}{t_2 - t_1}.$$

TABLE I.—RESULTS OF THE TESTS.

Index Letter for Curves.	Name of Material.	Weight of Sample (including Tin)	Total Fall of Temperature in 120 Minutes.	Thermal Conductivity in Absolute Measure.	Conductivity as compared with Dry Still Air.
		Lbs. Oz.	° Cent.		
A	Dry air	..	6·0	0·0000558	1·00
B	Fossil meal composition . . .	7 2	21·5	0·0002689	4·82
E	Cement with hair-felt[1] . . .	5 15	30·0	0·0003613	6·47
C	Silicate cotton,[2] or slag wool .	..	29·0	0·0003875	6·95
D	Kieselguhr composition . . .	7 13	29·0	0·0004336	7·77
G	Papier maché composition (*a*) .	7 6	35·5	0·0004424	7·93
F	Fibrous composition (flax, hemp, cow-hair and clay). . . .	9 9	34·5	0·0004550	7·98
H	Papier maché composition (*b*) .	8 12	37·5	0·0005019	8·99

Engineers when about to select non-conducting coverings for boilers, steam-pipes, or freezing-machines, must take many other things into consideration besides the value of the material as a non-conductor of heat. They must also take into account the first cost, appearance, and durability of the substance, as well as its weight, volume, and necessary thickness; the ease with which it can be removed for the repair of a leaky joint and replaced, its inodorousness when wet or dry, its incombustibility, non-liability to crack, and capability of resisting moisture. These, and such considerations, however, form no part of the present Paper, but the Author has pleasure in referring members to the other Papers enumerated in Appendix I, more especially to that by Professor Ordway, wherein these points are treated and discussed at length. In conclusion, the Author desires to thank Messrs. William J. Dale, George C. Laird, Andrew Gray, and David A. Ramsay for help with the experiments, drawings, and data for the Paper.

The Paper is accompanied by two drawings and a photographic print, from which the *Figs.* in the text have been prepared.

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[1] The outside diameter of sample E was about ¼ inch smaller than the inside diameter of the middle tin case, $T C_2$. It had consequently a slight advantage over the other samples in having a thin layer of air between its outer surface and the tin case $T C_2$.

[2] The silicate cotton was pressed together tightly, and thus its conductivity appears greater than would have been the case had it been more loosely packed.

APPENDIXES.

APPENDIX I.

Accounts of Previous Experiments.

In 1879 Mr. W. J. Bird, in a Paper[1] on "Condensation in Steam Pipes," described experiments on five substances, viz., woollen-felt, sawdust, fir-wood, coal-ashes and plaster. The temperatures on the outside surface of these non-conductors, which covered a 4-inch pipe filled with steam at 212° F., were noted and compared with temperatures on the outside of a bare pipe. In a second Paper,[2] by the same Author, on "Non-conducting Coverings for Steam-Pipes," six materials, viz., silicate cotton applied in three different ways, Toope covering (composed of asbestos, compressed paper and hair-felt), a composition of a plastic fibrous nature, and hair-felt were compared. The temperatures were taken as before, and the heat-units lost per foot length of pipe per hour were calculated. The saving in fuel effected per annum by covering 1,000 feet of steam-piping with the several materials dealt with in the Paper was also computed. A third Paper[3] by Mr. Bird, on "Non-conducting Coverings for Boilers and Steam-pipes," gives the results of tests of seven materials, viz., Dade silicate cotton, Dade silicate cotton composition, Toope covering, Burnett composition, Jones silicate cotton, and eagle cement and hair-felt. In a Paper[4] on "Transmission of Power by Steam," Messrs. Liddell and Merivale describe a successful attempt at Broomhill Colliery to convey power by means of steam to a pumping-engine situated 1,294 yards from the boiler, the steam-pipes, traps, and engine being covered with the composition indicated by the letter G in the Paper. In a Paper[5] on the same subject, Prof. J. H. Merivale deals with the extension and covering of the steam-piping at Broomhill Colliery, and demonstrates that power may be conveyed by steam in coal-pits for a distance of from 1,200 to 1,500 yards as economically as by ropes or by compressed air if the pipes are properly lagged with a good non-conducting material.

In 1881 Mr. Charles E. Emery, Ph.D., gave a Paper[6] on "Experiments with Non-conductors of Heat," wherein the results of his tests on fourteen different substances, some of which have been entered in the Table, p. 299, are given. The apparatus consisted of a boiler, 4 feet in diameter and 12 feet long, constructed with three 10-inch tubes. Into these tubes were placed smaller tubes to receive steam, and around the inner tubes were placed the non-conducting substances; water being circulated through the larger shell outside of the outer tubes. The results were shown by the amount of steam condensed in the inner tubes, the water of condensation being conducted to small cylindrical vessels, each provided with a glass gauge.

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[1] Transactions North of England Inst. of Mining and Mechanical Engineers, vol. xxix., 1879–80, p. 7.

[2] *Ibid*, vol. xxxi., 1881–82, p. 77.

[3] *Ibid*, vol. xxxii., 1882–83, p. 35.

[4] *Ibid*, vol. xxxv., 1885–86, p. 159.

[5] *Ibid*, vol. xxxvii., 1886–87, p. 13.

[6] Transactions American Society of Mechanical Engineers, vol. ii., 1881, p. 34.

In 1884 Prof. John M. Ordway, of Boston, Mass., described, in a Paper[1] on "Experiments upon Non-conducting Coverings for Steam-Pipes," tests of a great variety of substances by three methods; (1) by measuring the temperatures on the outside of the coverings; (2) by measuring the weight of steam condensed in a certain time over a certain length of covered pipe; and (3) by a calorimeter. His results are stated in such a way that the Author was unable to include them in the appended Table.

In 1884 Mr. J. J. Coleman gave[2] the results of a series of experiments (see Table below) on nine substances tested by means of a modification of Lavoisier ice calorimeter. The object of the experiments was to find the substance which would make the best covering for the "Bell-Coleman Freezing-Machines," now so much used in the transport of meat from the United States and the Colonies.

In 1884 Mr. D. K. Clark, M. Inst. C.E., reported[3] to the National Smoke Abatement Institution the results of tests carried out at the works of Messrs. Samuel Hodge and Sons, Millwall, of seven substances as compared with a bare pipe. The results are not stated, however, in such a form that they can be included in the Table below.

In 1891 Mr. Hepworth Collins, read a Paper on "The Comparative Value of various Substances used as Non-conducting Coverings for Steam-Boilers and Pipes,"[4] giving results of experiments in which a mass of each material to be experimented upon, 1 inch thick, was carefully prepared and placed on a perfectly flat iron plate or tray, which was then maintained at a constant temperature of 310° F. The heat transmitted through each non-conducting mass was calculated in lbs. of water heated 10° F. per hour.

RESULTS OF DIFFERENT EXPERIMENTS ON THE HEAT CONDUCTIVITIES OF VARIOUS SUBSTANCES.

(Silicate cotton being taken as 100.)

Substance.	C. E. Emery, 1881.	J. J. Coleman, 1884.	W. H. Collins, 1891.	Prof. Jamieson, 1894.
Fossil meal composition	..	..	..	70
Cement with hair-felt	83	..	..	93
Silicate cotton, or slag wool	100	100	100	100
Hair-felt or fibrous composition	..	117	114	112
Papier maché	..	..	147	111
Kieselguhr composition	..	136	..	112
Sawdust	122	163	142	..
Charcoal	132	140	..	..
Cotton wool	..	122	..	..
Sheep's wool	..	136	..	..
Pine wood (across the grain)	150	..	..	..
Loam	..	..	..	..
Gasworks breeze or coal ashes	240	230	299	..
Asbestos	229	..	179	..

[1] Transactions American Society of Mechanical Engineers, vol. v., 1883-84, p. 73.

[2] Proceedings Philosophical Society of Glasgow, vol. 15, 1883-84, p. 90.

[3] *The Engineer*, vol. lvii., 1884, p. 65.

[4] Report of the British Association for the Advancement of Science, Cardiff, 1891, p. 780.

APPENDIX II.

Tests of Lagging for Steam-pipes.

The Author has received permission to publish for the first time the following account of tests which have recently been made at an important works, the name of which, however, he has been requested to withhold. The results form an interesting comparison with those of the specimens D and G in the Paper.

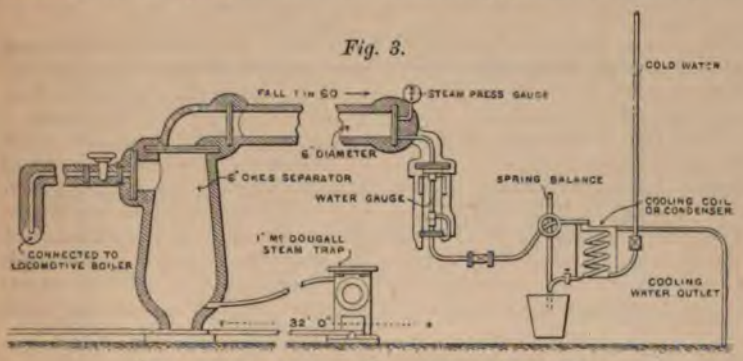
Steam from a locomotive boiler (which was doing no other work), was passed through a separator to ensure its being delivered perfectly dry, into a 32-foot length of wrought-iron steam-pipe of 6 inches internal diameter and ¼ inch thickness, *Fig. 3*. This pipe for the whole of its length was covered with the non-conducting material to be tested. The condensed steam accumulated in a water-gauge placed at its lower end, from which it could be drawn off through a stop-cock into a receiver freely hanging on a spring-balance. The water-level in the gauge-glass was maintained as constant as possible, and the water

Results of Tests.

Substances.	Pressure of Steam—Lbs. per Square Inch.	Lbs. of Steam Condensed per Square Foot of Internal Surface of Pipe per Hour.	Thermal Units radiated from Pipe per Hour.		Amount of Steam Condensed in Lbs. per Hour.	Percentage of Increase of High-Pressure Steam Condensed.	Remarks.
			Per Square Foot of Internal Surface.	Per Square Foot of External Surface.			
Naked pipe . . .	150	1·169	1,129	815	..	..	.. ..
	60	0·937	905	653	..	..	.. ..
Pipe covered with 2 inches of the material (G) in the Author's tests . .	150	0·294	284	156	..	..	Tough, hard, and dark brown in colour, and makes a neat cover.
Pipe covered with 2 inches of the material (G) and ¾ inch of hair-felt . .	150	0·216	212	98	11·1	..	.. ..
Pipe covered with 2 inches of the material (D) in the Author's tests . .	150	0·226	218	119	11·6	34·8	Very friable and difficult to apply without numerous cracks. Light yellow in colour. Does not last long.
	60	0·166	160	89	8·6		
Pipe covered with 2 inches of the material (D) and ¾ inch of hair-felt . .	150	0·188	182	86	9·7	49·0	The felt improves its appearance and possibly also its lasting qualities.
	60	0·125	121	56	6·5		
Pipe covered with ¾ inch of cork strips and two layers of canvas	150	0·198	191	132	10·2	32·4	Easily applied, making neat cover. Joints easily accessible, but may possibly perish with the heat.
	60	0·152	146	102	7·7		

was cooled to atmospheric temperature in a condenser before being weighed. Readings of the spring-balance were taken every quarter of an hour, and

Fig. 3.



APPARATUS FOR TESTING LAGGINGS OF STEAM-PIPES.
Scale, ½ inch to 1 foot.

were plotted upon curves. The trials were made at steam-pressures of 60 lbs. and 150 lbs. per square inch. The results are given in the Table on p. 300.

APPENDIX III.

TESTS OF ASBESTOS AND KIESELGUHR COMPOSITIONS.

The conductivities of asbestos and kieselguhr composition are indicated by the following account of experiments, which is taken from a letter received by the managing agents of the British India Steam Navigation Company from their Superintending Engineer at Calcutta, Mr. John G. Dobbie, and published by their permission:—

The experiments were made with two boiler-tubes—3½ inches in outside diameter and 7 feet long, closed at both ends, and covered with a thickness of 2 inches of asbestos and kieselguhr composition respectively. The tubes were suspended side by side, and steam was admitted at the top, a gauge-glass being fitted at the bottom of each by which the amount of condensation inside the tubes could be accurately observed. Steam at a pressure of 30 lbs. per square inch was used in the tubes. In the first trial, which lasted one hour, 12·375 inches of water were condensed in the tube covered with asbestos, and 8·375 inches in that covered with kieselguhr composition, showing 33 per cent. less water condensed with kieselguhr composition. In the second trial, of one hour also, the condensation was noted every fifteen minutes, and gave the results shown in Table on p. 302.

From these, and from several other tests which the Author has investigated since conducting his experiments, he has come to the conclusion that hard-pressed asbestos paper or cloth conducts heat much better than silicate cotton, felt, hair, wool, or some of the kieselguhr compositions. Fibrous porous matter acts well as a non-conductor mainly in virtue of the occluded and entrapped air, and hence, the looser the asbestos and other fibrous materials are laid on, the better will they prevent radiation of heat. Asbestos paper applied

between a high-pressure steam-pipe and hair-felt fails to prevent the hair from being scorched. Its incombustibility is evidently frequently assumed to include the distinct and separate property of non-conductivity.

RESULTS OF TESTS.

——	Asbestos.	Kieselguhr Composition.
	Water Condensed in Inches.	Water Condensed in Inches.
After 15 minutes . . .	4½	2½
„ 30 „ . . .	3⅝	2⅜
„ 45 „ . . .	3⅜	2¼
„ 60 „ . . .	3⅜	2⅛
Totals in one hour . .	14½	9½

This experiment shows a saving of 36 per cent. in favour of kieselguhr composition.

(Paper No. 2883.)

Brief Notices of Works.[1]—Portland Harbour; The Severn Tunnel; The Forth Bridge; The River Clyde; The River Tyne; The Tower Bridge.

By Leveson Francis Vernon-Harcourt, M.A., M. Inst. C.E.

A few of the most important engineering works in Great Britain have not formed the subjects of Papers presented to the Institution, occasionally, in the case of a work of general public interest, in consequence of a full account having been published in the form of a book immediately after its completion, as well as from other causes. It appears desirable, however, that the Minutes of Proceedings should contain, in some form, references to such works, in order that they may furnish as complete a record as practicable of engineering science and progress. These notes, it is hoped, will, in some measure, fill gaps resulting from the regrettable absence of full descriptions of a few notable engineering works, and also assist engineers in their search for information upon them.

Portland Harbour.

The bay in which Weymouth is situated, is sheltered by Portland Island and the adjacent coast, from all quarters except from south-east to east. This site was accordingly selected when the establishment of harbours of refuge, at suitable points along the coasts of Great Britain, was engaging the attention of the Government. Works were commenced in 1847 for protecting 2,130 acres of water at low tide from easterly winds, in accordance with the designs of the late Mr. J. M. Rendel, and under the control of the Admiralty. The breakwaters providing the necessary shelter from the south and east were constructed, by the aid of convict labour, of Portland stone quarried on the island; and

[1] These descriptions have been submitted to and approved by the engineers (or their representatives) of the several works referred to.

they consist, for the most part, of a rubble mound, which was tipped into the sea from wagons drawn by locomotives, running on temporary staging erected over the site, supported on piles, placed 30 feet apart, and provided with iron screws which penetrated the clay to a depth of 6 to 8 feet. The inner breakwater starts from the north-east corner of Portland Island, and extends in an easterly direction for a length of 1,900 feet, increasing the width of the sheltered area, and protecting it from the south-east. It is formed by a rubble mound, surmounted above low-water by a masonry superstructure providing a sheltered quay on the harbour side, with a jetty for coaling purposes.[1] The outer detached breakwater is separated from the inner breakwater by an opening, 400 feet wide, affording a southern entrance to the harbour, which was bridged over by means of the staging during construction. After following the line of the inner breakwater for a short distance, the outer breakwater curves round to a northerly direction, and terminates in a depth of 9 fathoms, with a total length of 6,200 feet. It is entirely formed of a rubble mound, composed of stones of various sizes with a fair proportion of stones of 6 tons to 8 tons in weight; and it has been raised a few feet above high water of spring-tides. Masonry pierheads were built at the end of the inner breakwater and at both extremities of the detached breakwater, founded 24 feet below low water; and forts have been erected on the outer ends of the breakwaters to guard the entrances to the harbour.

The harbour has been left open to the north for its entire width, being fully sheltered in this direction by the mainland, so that access is easy on rounding the northern end of the outer breakwater. The late Sir John Coode was the resident engineer on the harbour works at their commencement; he was appointed engineer-in-chief on the death of Mr. Rendel in 1856, and remained in charge of the works until their completion in 1872. The quantity of rubble stone deposited in the mounds forming the breakwaters, amounted to 5,750,000 tons; plant was provided by the contractors for tipping 3,000 tons per day in the mound, but the actual amount furnished varied considerably according to the number of convicts employed in quarrying and loading the wagons; and the maximum quantity deposited in one year was 553,400 tons, in 1860. The total cost of the works, including that of the convict department, reached £1,040,000.

The memoirs of Mr. J. M. Rendel and Sir John Coode, in the

[1] Minutes of Proceedings Inst. C.E., vol. xxii. Plate 9A, Fig. 9.

Minutes of Proceedings,[1] contain references to Portland Harbour; some information about the method of constructing the breakwaters, and the employment of convict labour, was given by Sir John Coode in evidence[2] before the select committee on "Harbours of Refuge" in 1857; and particulars of the breakwaters, and a section of the inner breakwater, were published, about the year 1863, in Tomlinson's "Cyclopædia of Useful Arts and Manufactures."[3] A description of the harbour works, with a plan of the harbour and sections of the breakwaters, is given in "Harbours and Docks;"[4] and details relating to the progress of the works, and the expenditure on them, are contained in the printed quarterly reports made by the engineers to the Admiralty up to 1866, and subsequently to the Board of Trade, during the construction of the harbour.[5]

The Severn Tunnel.

The Great Western Railway system west of Bristol was formerly separated, south of Gloucester, by the Severn and its estuary, from the lines between Gloucester and the South Wales ports, as well as from the western lines between Hereford and North Wales, Liverpool, Manchester and the north. This want of connection was only partially remedied by a steam ferry across the estuary of the Severn, from New Passage to Portskewett, with connecting branch lines, which involved transhipment of passengers and goods. A tunnel under the Severn estuary was, accordingly, proposed by Mr. Charles Richardson in 1871, to provide for through traffic, and was authorised in 1872; and the works were commenced by the Great Western Railway Company in 1873, by sinking a shaft, 15 feet in diameter and lined with brickwork, near the Monmouthshire bank of the Severn, to a depth of 200 feet. The site selected for the tunnel is a short distance below the ferry, and about two miles below the mouth of the Wye, where the width of the estuary at high tide is about $2\frac{1}{4}$ miles, and the main low-water

[1] Minutes of Proceedings Inst. C.E., vol. xvi. p. 139, and vol. cxiii. p. 335.

[2] "Select Committee on Harbours of Refuge, Minutes of Evidence, 1857," pp. 89–114, and Plate 3.

[3] "Cyclopædia of Useful Arts, Manufactures, Mining and Engineering," edited by Charles Tomlinson, vol. iii., Appendix, "Portland Breakwater," pp. 551 and 552.

[4] "Harbours and Docks," L. F. Vernon-Harcourt, 1885, pp. 188–193, and pp. 256 and 257, and Plate 3, Fig. 11, Plate 6, Fig. 2, and Plate 7, Fig. 11.

[5] "Harbours of Refuge, Detailed Statements and Quarterly Reports of the Engineers."

channel is 2½ furlongs wide, the maximum depth of the estuary at high water of springs at this place being 95 feet, with a tidal rise of 37 feet. The strata traversed by the tunnel consist of conglomerate, limestones, carboniferous beds, sandstone, marl, gravel, and sand, having a considerable dip; and the least thickness of soil between the top of the tunnel and the deepest part of the channel is 44¾ feet. The total length of the tunnel is 4 miles 624 yards.

After the Monmouthshire shaft had been sunk, a heading 7 feet square was driven under the river, rising with a gradient of 1 in 500 from the shaft on the Monmouthshire shore, so as to drain the lowest part of the tunnel. Near to the first, a second shaft was sunk, and tubbed with iron, in which the pumps were placed for removing the water from the tunnel works, connection being made by a cross-heading with the heading from the first shaft. There was also a shaft on the Gloucestershire shore; and two shafts inland from the first on the Monmouthshire side, to expedite the construction of the tunnel. Headings were then driven in both directions along the line of the tunnel, from the four shafts; and the drainage heading from the old shaft was continued, in the line of the tunnel, under the deep channel of the estuary and up the ascending gradient towards the Gloucestershire shore, till, in October 1879, it had reached to within about 130 yards of the end of the descending heading from the Gloucestershire shaft. During this period, though the work had progressed slowly, no large quantity of water had been met with in any of the headings, in spite of their already extending under almost the whole width of the estuary. On the 18th October 1879, however, a great spring was tapped by the heading which was being driven landwards from the old shaft, about 40 feet above the level of the drainage heading; and the water poured out from this land spring in such quantity that, flowing along the heading, falling down the old shaft and thus finding its way into the drainage heading and the long heading of the tunnel under the estuary in connection with it, it flooded the whole of the workings in communication with the old shaft, which it also filled within twenty-four hours from the piercing of the spring. Under these circumstances, the directors appointed their consulting engineer, the late Sir John Hawkshaw, to be engineer-in-chief of the works; and the contract for the completion of the tunnel was entrusted to the late Mr. T. A. Walker.

To obtain increased security against any influx of water from the deep channel of the estuary into the tunnel, the proposed level portion of the tunnel, rather more than a furlong long under this part, was lowered 15 feet, by increasing the descending gradient on

the Monmouthshire side from 1 in 100 to 1 in 90, and lowering the proposed rail-level on the Gloucestershire side 15 feet throughout the ascent, so as not to increase the gradient of 1 in 100 against the load. A new shaft, 18 feet in diameter, was sunk slightly nearer the estuary on the Monmouthshire shore than the old one; two shafts also were sunk on the land side of the great spring, for pumping purposes; and additional pumping-machinery was erected. The flow from the spring into the old shaft was arrested by a shield of oak fixed across the heading; and at last, after numerous failures and break-downs of the pumps, the headings were cleared of water, after a diver, supplied with a knapsack of compressed oxygen, had closed a door in the long heading under the estuary; and the works were resumed nearly fourteen months after the flooding occurred. The great spring was then shut off from the workings by a wall across the heading leading to the old shaft; and, owing to the lowering of the level of the tunnel, a new drainage heading had to be driven from the bottom of the new shaft at a lower level, which was made 5 feet in diameter and lined with brickwork; whilst the old drainage heading was enlarged to 9 feet in diameter, and lined with brickwork, so as to aid in the permanent ventilation of the tunnel. The lowering of the level, moreover, converted the bottom tunnel headings into top headings, so that along more than a mile of the tunnel, the semicircular arch, 26 feet in diameter, was built first; and then, after lowering the headings, the invert was laid and the side walls were built up. Bottom headings were driven along the remainder of the tunnel; and the work was expedited by means of break-ups. Ventilation was effected in the works by a fan 18 inches in diameter and 7 feet wide, fixed at the top of the new deep shaft; the rock was bored by drills worked by compressed air; the blasting was eventually effected exclusively by tonite, owing to its being freer from deleterious fumes than any other explosive; and the workings were lighted by Swan and Brush electric lamps. The tunnel is lined throughout with vitrified brickwork, between $2\frac{1}{4}$ feet and 3 feet thick set in cement, and has an invert $1\frac{1}{2}$ foot to 3 feet in thickness; the lining was commenced towards the end of 1880; the headings under the river were joined in September 1881; and the last length of the tunnel, across the line of the great spring, was completed in April 1885.

Water came in from the river through a hole in a pool of the estuary, close to the Gloucestershire shore, in April 1881, during the lining of a portion of the tunnel, but fortunately before the

headings were joined. This influx was stopped by allowing the water to rise in the tunnel to tide-level, to prevent the enlargement of the hole, which was then filled up at low water with clay, weighted on the top with clay in bags. The great spring broke out again in October 1883, and flooded the works a second time; but within four weeks the water had been pumped out, and the spring again imprisoned. During this period, an exceptionally high tide, raised still higher by a south-westerly gale, inundated the low-lying land on the Monmouthshire side of the estuary, and flowing down one of the inland shafts, flooded a section of the tunnel; but the pumps removed this water within a week.

In order to construct the portion of tunnel traversing the line of the great spring, the water was diverted into a side heading, below the level of the tunnel, leading to the old shaft, whence it was pumped; and the fissure below the tunnel was filled with concrete, over which the invert was built. An attempt to imprison the spring, on the completion of this length of tunnel, having resulted in imposing an excessive pressure on the brickwork, leading to fractures and leakage, a shaft, 29 feet in diameter, was sunk at the side of the tunnel at this point in 1886, and pumps were erected powerful enough to deal with the entire flow of the spring.

The tunnel was opened for traffic in December 1886, and gives access to a double line of railway connecting the lines converging to Bristol with the South Wales Railway and the western lines. The pumping-power provided at the shaft connected with the great spring, and at four other shafts, is capable of raising 66,000,000 gallons of water per day, the maximum amount pumped from the tunnel being 30,000,000 gallons a day. The ventilation of the tunnel is effected by fans placed in the two main shafts, on each bank of the estuary; and the fan in the Monmouthshire shaft is 40 feet in diameter and 12 feet wide. The tunnel gives passage to a large traffic, numerous through trains between the north and south-west of England making use of it.

A very full and graphic account of the progress of the tunnel works, and the difficulties encountered, was published by the late Mr. T. A. Walker, soon after the opening of the tunnel for traffic.[1]

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[1] "The Severn Tunnel; its Construction and Difficulties, 1872–1887," Thomas A. Walker, 1888. Brief accounts of the works are also given in a Paper on "The Severn Tunnel Railway," J. C. Hawkshaw, British Association Report, Montreal, 1884, p. 884, and in "Achievements in Engineering," L. F. Vernon-Harcourt, 1891, pp. 96 and 100–106.

The Forth Bridge.

The Firth of Forth obliged the railways from England converging to Edinburgh to make a long detour by Stirling, in order to reach Perth, Dundee, Aberdeen, and other places on the east side of Scotland, or to convey their traffic by the inconvenient mode of a ferry across the Firth at Queensferry. The contraction of the Firth of Forth at Inverkeithing, by the projection of the shore at North Queensferry, and the existence of the rocky island of Inchgarvie in mid-stream at this point, dividing the channel into two equal portions, rendered this site the only suitable one for a bridge for many miles up the Forth; whilst below, the width of the estuary increases rapidly to the North Sea. The high ground, moreover, on each side of the contracted channel was favourable for the approaches of a high-level bridge, and unfavourable for access to a tunnel under the Forth, which would have been obliged to traverse uncertain strata at a considerable depth, as the depth of the main channels at this place exceeds 200 feet. Accordingly, though a tunnel was proposed early in this century, and the feasibility of a tunnel was discussed in considering the schemes for more direct railway communication across the Forth, the construction of a bridge was preferred. Several schemes for bridges have been proposed from time to time; and a steel suspension-bridge for crossing the Forth at the site of the present bridge, with two spans of 1,600 feet, was authorised in 1873. The foundation of one of the towers of this bridge had been commenced when the overthrow of the large spans of the Tay Bridge by a gale, in December, 1879, led to the abandonment of the suspension-bridge, and the adoption of a design by Messrs. Fowler and Baker for a steel cantilever-bridge, the construction of which was authorised in 1882.

The bridge, as carried out, provides two central spans of 1,710 feet each, and two side spans of 680 feet, across the two channels on each side of Inchgarvie Island, with a clear headway of 150 feet at high water for the central 500 feet of each large span. The main portion of the bridge consists of three double, symmetrical cantilevers resting on piers on the shore side of each of the deep channels, and on a central group of piers on the island. These stretch out over the two channels, viaducts on each bank connecting the bridge with the high land rising on each side of the Forth. The interval between the cantilevers, over the centre of each channel, is spanned by a pair of lattice-girders, 350 feet in length, supported on the ends of the cantilevers. The length of

the main portion is 5,330 feet; but the total length of the bridge, including the approach viaducts on each side, is 8,296 feet. The rise of spring-tides at Queensferry is 18 feet; and the contraction in width of the Forth at this point creates strong tidal currents. The greatest wind-pressure recorded at the site since the commencement of the works, was 41 lbs. on a square foot in February 1887, with a south-westerly wind.

The works were commenced early in 1883. Each of the three cantilevers rests on four circular masonry piers, on which the four nearly vertical central steel columns of the cantilevers stand, 12 feet in diameter and of $\frac{5}{8}$-inch plates. The two inland piers on the northern or Fife shore were built upon a foundation of Whinstone rock on land; and the two other Fife piers adjoining the channel, and the two northern Inchgarvie piers were built under the shelter of plate-iron cofferdams on the sloping Whinstone rock cut back in steps, as the sites of these piers were submerged at high water, and were partially below low-water level. The two southern Inchgarvie piers and the four Queensferry piers were founded wholly under low water by means of circular plate-iron caissons, 70 feet in diameter at the bottom, which were floated into place and sunk to a solid foundation by weighting them with concrete. The bottom was excavated by the aid of compressed air, within a working-chamber 7 feet high, lighted by electricity, the caisson being provided with a strong cutting curb round its lower edge. As the two Inchgarvie caissons had to be sunk on to a sloping surface of rock, mounds of sand-bags and piers of concrete-bags were laid along the lower part of the rock to support the outer portion of the cutting-edge of the caisson, widened out by a timber frame flush with the cutting-edge, when its inner portion touched the rock. The upper part of the rock was then bored and blasted by the men in the working-chamber, till the rock had been nearly levelled over the site of the caisson. To save rock excavation and further sinking of the caisson, the work was stopped when only a slight depression remained near the outer edge; and the gap between the edge of the caisson and the rock was closed by iron plates, and the hollows were filled with concrete in bags grouted with cement. The four Queensferry caissons were sunk into firm boulder clay overlaid with mud, so that in this case the excavation could be carried on simultaneously over the whole area of the working-chamber. In sinking through the mud, great care had to be taken to prevent a sudden descent of the caisson in the soft bottom; and the mud was mixed with water in a hollow formed in the bottom, and was then ejected

through a pipe outside the caisson by the pressure of the air in the chamber. One of the Queensferry caissons when placed over its site, stranded on the mud at low tide, and became embedded in it during an exceptionally low tide on the 1st January, 1885. It tilted over somewhat, and, not rising with the tide, was filled with water. A rent was formed in the plates of the caisson by the pressure outside on pumping out the water; but eventually, in October 1885, having been sheathed with timber, it was floated again, lined with brickwork, and sunk like the others. The Inchgarvie caissons were sunk to depths of 63¾ feet and 72 feet below high water, and the Queensferry caissons to depths of 71 feet to 89 feet, through 33 feet to 49 feet of mud, clay and boulder-clay. When the sinking was completed, the working-chamber was filled with concrete, with which the caisson was also filled to low-water level. The piers, formed of rubble masonry faced with granite, were built on these foundations, tapering from 55 feet to 49 feet in diameter, to a height of 18 feet above high water, and carried the bed-plates held down by bolts built into the masonry. The first foundations were commenced in June 1883, and the last pier was completed three years later; and, omitting the delay caused by the accident, the time occupied between launching a caisson and the completion of the pier varied between eight months and fourteen months, and averaged ten-and-a-half months.

The erection of the central portion of the cantilevers was commenced on the completion of the piers and the fixing of the bed-plates. The skewbacks were first proceeded with; and then the horizontal tubes connecting them were put together on staging, and were riveted up. The nearly vertical columns and the diagonal strut-tubes were then gradually built up, with their cross-girders and diagonal girders for bracing them together, by the aid of steam derrick-cranes raised on staging; the riveting of the tubes being effected by hydraulic tube-riveting machines, encircling and travelling along the tubes, and enclosed by a wire cage. As soon as the vertical columns and the struts had reached a height of about 50 feet, lifting-platforms were provided which were raised by hydraulic rams in the vertical tubes; and these platforms, carrying cranes and goliaths for lifting the pieces, served to raise the central portions in stages to their full height of 330 feet.[1] As none of the main members forming these central towers were actually vertical, they tended to deflect during erection under their own weight; and even the sun's heat caused temporary deflections

[1] "Hydraulic Appliances at the Forth Bridge Works," E. W. Moir, Minutes of Proceedings Inst. C.E., vol. xci. p. 402, and Plate 9.

in these unconnected portions. Moreover, the main columns, when carrying the lifting-platforms, were subject to distortions and deflections by a strong side-wind. Accordingly, temporary struts and bracing were needed to keep the unconnected members in place; and their positions had to be carefully checked and adjusted before the junctions of the several parts were effected.

As no staging could be erected in the deep channels on each side of the island, the projecting cantilevers on each side of the central towers had to be built out; and the tubes forming the bottom compression members of the cantilevers, 12 feet in diameter and of 1¼-inch plates, were commenced first, starting from the piers. The bottom member, though curved in outline, was formed of straight lengths of tubes, joined together at a gradually diminishing angle to the horizontal, for facility of construction. For building out these tubes, a square cage was constructed round the tube, which could be shifted forwards in pieces as the work advanced, and on which a hydraulic crane was placed for handling the plates. A hydraulic tube-riveting machine within the cage fastened up the plates. The tube was temporarily supported by chains and ties, till the tube-struts and lattice-ties of the first bay of the cantilever could be completed and connected by the aid of lifting-platforms; and the top lattice-girder members of the cantilever were built out by cranes from the top of the tower. The successive bays of the cantilevers were then gradually built out on each side by means of cranes; and the internal viaduct was simultaneously carried forward, on which two lines of way, and a footway on each side, are borne by two longitudinal lattice-girders braced together and supported at intervals on the cantilevers by trestles and cross-girders. Finally, on the completion of the cantilevers, the central lattice-girders, of 350 feet span over the centre of each channel, were built out from each end of the adjacent cantilevers, and were joined in the centre of the span. To provide for longitudinal expansion and contraction, rocking columns were interposed between one end of the central girders and the cantilevers; and the shore extremities of the other two cantilevers were left free to slide on their abutments. The weight of steel in the cantilever portion of the bridge amounts to 51,000 tons.

With a wind-pressure of 56 lbs. on a square foot, the lateral pressure against one of the large spans amounts to 2,000 tons. To provide for this pressure, in addition to diagonal wind-bracing in the cantilevers, the cantilevers at the central towers, where the greatest surface is exposed, have been widened to 120 feet at the base, decreasing to a width of 33 feet at the top of the towers; and these widths are reduced at the ends of the cantilevers to 32 feet at the

bottom, and 22 feet at the top, the inward slope upwards of the sides of the cantilevers, of about 1 in $7\frac{1}{2}$, being maintained uniform throughout.

As the dead weight of one of the large spans is about 16,000 tons, and the maximum moving load in ordinary daily working is only 800 tons, the chief strains on the bridge are due to its own weight. Under the test-load of six engines and tenders with eighty-eight trucks loaded with iron, imposing a weight of 1,802 tons on a length of 896 feet of the bridge, the maximum deflection, at a high speed, was only 7·65 inches on the 1,710-foot span. Each projection of the cantilevers is 680 feet long; and the central portion of the shore cantilevers is 155 feet in length. Since the river extremity of each of these cantilevers has to bear half the weight of the central girders, the portion projecting over the shore, in each case, has been made heavier, and has also been weighted at its end so as to counterpoise the half-weight of the girders. Moreover, as the river end is liable to be further weighted by two crossing trains, a further counterpoise has been added at each shore end, exceeding the maximum train-load by 200 tons to ensure the maintenance of the balance. The Inchgarvie cantilever is, on the contrary, equally balanced as regards the dead load by half the weight of the central girders at each extremity. As, however, the maximum train-load of two trains crossing at one extremity cannot in this case be counterpoised at the other end, this cantilever has been strengthened by making its central portion 270 feet in length.

The bridge was opened for traffic in March 1890, its erection having occupied about seven years. Sir John Fowler, Bart., Past-President Inst. C.E., and Sir Benjamin Baker, K.C.M.G., Vice-President Inst. C.E., superintended the construction of the bridge as engineers-in-chief; and Sir William Arrol was the principal contractor. The works, including the approach railways, parliamentary expenses and interest during construction, cost approximately £3,000,000.

The works were fully described and illustrated in *Engineering* on their completion, and this description has been reprinted in the form of a book;[1] and several other accounts of the bridge have been published.[2]

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[1] "The Forth Bridge," W. Westhofen, reprinted from *Engineering*, February 28th, 1890.

[2] "The Forth Bridge," B. Baker, British Association Report, Southampton Meeting, 1882, p. 419, and Plate 8; and *Engineering*, 1884 (2), pp. 211 and 223. "Bridging the Firth of Forth," B. Baker, Proceedings of the Royal Institution, 1887, vol. xii. p. 142; "Die Forth-Brücke," G. Barkhausen, Berlin, 1889. "The Forth Bridge," P. Phillips, Edinburgh, 1890.

The River Clyde.[1]

In 1873, a Paper on "The River Clyde" was read by Mr. James Deas before the Institution,[2] giving an account of the improvements effected in the river from the commencement of the works until 1872. During the twenty-three years, however, that have elapsed since the termination of that record, considerable progress has been made in the dredging of the river and the extension of the harbour of Glasgow, under the direction of Mr. Deas, the engineer-in-chief to the Trustees of the Clyde Navigation.

Since 1872, dredging for the removal of the deposit, which would otherwise accumulate, and for increasing the navigable depth in the river, has been carried on continuously, and more extensively than before, by five bucket-ladder dredgers, aided since 1880 by a 10-ton steam digger, and served by a fleet of twenty-two steam hopper-barges conveying the dredged materials and depositing them in deep water in the Firth of Clyde. The greatest amount dredged from the river and harbour in a year, until 1872, was 992,350 cubic yards, removed in 1871–72; but since then, till the present time, the amount raised in a year has only on three occasions fallen below 1,000,000 cubic yards, and has averaged 1,320,600 cubic yards until 1894, the maximum quantity dredged in a year having reached 2,310,980 cubic yards in 1893–94. Moreover, whereas in the twenty-eight years between 1844 and 1872, the total quantity dredged amounted to 14,609,400 cubic yards; in the twenty-two years between 1872 and 1894, as much as 29,054,300 cubic yards of materials have been removed. The minimum available depth below Glasgow, at high water of spring-tides, has been increased from about 23 feet in 1872 to 27½ feet in 1894; but in contrasting the large amount dredged with this increase in depth, it must be remembered that the channel has been widened as well as deepened, and that the quantities recorded include dredging in the formation of the dock extensions, and also the removal of deposit from the river and docks, which averages between 600,000 yards and 700,000 cubic yards in the year. The deposit of the dredged material, which subsequently to 1862 was effected in deep water in Loch Long, 27 miles from Glasgow, has had to be discontinued, owing to the alleged nuisance caused by the sewage of Glasgow forming part of the dredgings. A new depositing ground, accord-

[1] "Reports on the Improvement and Management of the River Clyde and Harbour of Glasgow from 1755 to 1853." 8vo. Glasgow, 1854.

[2] Minutes of Proceedings Inst. C.E., vol. xxxvi. p. 124, and Plates 19–23, and "The River Clyde," James Deas, Glasgow, 1876.

ingly, three miles south-south-west of Garroch Head, and about 46 miles from Glasgow, has been recently selected; and six twin-screw hopper-barges, two of 1,000 tons and four of 1,200 tons capacity, steaming at an average speed of 10½ knots an hour, have been built to convey the dredged materials to this new site, in conjunction with the eighteen steam hopper-barges of 300 tons and 400 tons capacity previously employed. The deepening of the river since 1872 has resulted in a further lowering of the low-water line about 14 inches at Glasgow. A weir which obstructed the flow of the tide about half-a-mile above Glasgow Bridge, with its crest 2 feet below high water of spring tides, was removed in 1880.[1] On account, however, of the injury to the banks of the river along Glasgow Green and above that point, caused by the lowering of the water-level, involving a large outlay in repairs and maintenance, and the spoiling of that portion of the river for boating, a tidal weir is being erected by the Glasgow Corporation on the site of the old weir, similar to that across the Thames at Richmond.

The only dock at Glasgow in 1872 was the Kingston Dock of 5½ acres, on the south side of the river, as for a long time the quays constructed along the river afforded sufficient accommodation for the shipping. Since then, however, the quay accommodation has been largely increased by the opening of the Queen's Dock on the north side of the river, having an area of 33¾ acres; and the Cessnock Dock, with an outer basin giving access to three branch basins, affording an ample length of quay, is in course of construction on the south side of the river opposite the Queen's Dock, which when completed will add 36 acres to the dock-area. The dock-walls have been mostly built upon triple cylinders, 9 feet 7½ inches in external diameter and 36½ feet high, formed of rings of concrete, 2½ feet deep by 1 foot 11 inches wide, sunk into the alluvial ground and filled with concrete. Where, however, a depth of 28 feet at low water is to be afforded, a row of twin cylinders, 34 feet high, is placed behind the triple cylinders. The walls are built of concrete rubble faced with concrete ashlar, and coped with granite. The entrance to the Queen's Dock is 100 feet in width, and the entrance to the Cessnock Dock is 156 feet in width at its narrowest part; and they are quite open to the river, as the tidal rise at spring-tides at Glasgow is only 11 feet 2 inches. The first public graving-dock constructed by the Trustees, 565 feet long with a

[1] "The Weirs across the Clyde at Glasgow, their History and results of their Removal," James Deas, Glasgow, 1886.

depth of 22 feet 10 inches on the sill at spring-tides, was opened in 1875; and a second graving-dock, 575 feet long and 92 feet wide at the top, with a similar depth on the sill, was opened in 1886. A considerably longer graving-dock is being constructed to the south of the other two, opening into the outer basin of the Cessnock Dock, close to its entrance.

The traffic across the river below Glasgow Bridge is conducted by ten passenger ferry-steamers, and two vehicular and passenger ferry-steamers, one at Finnieston with an elevating deck [1] and the other at Govan.

The total expenditure of the Clyde Trust since 1770 has increased from £5,595,000 in 1872, to £14,751,000 in 1894; and the gross annual revenue has risen from £174,200 in the year 1872, to £371,976 in 1894, in which year the expenditure was £349,350, leaving a surplus revenue of about £22,000. The debt of the Clyde Trustees was £2,151,557 in 1872, and £5,267,325 in 1894. The tonnage of the shipping entering the port, which was 2,128,379 tons in 1872, reached a maximum of 3,778,541 tons in 1894.

Since the commencement of the improvement works in 1773, the Clyde has been deepened on the average about 23½ feet between Glasgow and Dumbarton; the bed of the river is now practically level from Glasgow to Port Glasgow; there is a depth of water of 16 feet to 20 feet in Glasgow Harbour at low water of spring-tides; and the low-water line has been lowered altogether 9½ feet at Glasgow by the dredging in the river. High water at Glasgow was two hours later than at Port Glasgow in 1800, and now the interval is only one hour. Moreover, even in 1858, a float placed in the river at Glasgow Bridge on the commencement of the ebb oscillated up and down the river for forty-three and a half tides before reaching Port Glasgow, 19½ miles down the river; whereas in 1881, floats started under the same conditions, travelled on an average 23½ miles down the river in only ten tides.[2]

Accounts by Mr. Deas of the improvement of the Clyde and the development of Glasgow Harbour have been published from time to time.[3] Details also relating to the progress of the works are

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[1] "Recent Types of Ferry-Steamers," A. Brown, Minutes of Proceedings Inst. C.E., vol. cxviii. p. 258, and Plate 6, Figs. 5 and 6.

[2] "Report on Tidal Velocities in the River Clyde between Glasgow and Greenock," James Deas, Glasgow, 1881.

[3] "The River Clyde and Harbour of Glasgow," James Deas, a lecture read at the Naval and Marine Engineering Exhibition, Glasgow, 1881; "The Clyde," Glasgow, 1884; "Report on the Deepening, Widening, and Improving of the

furnished in the engineer's quarterly reports to the trustees; and the annual expenditure, the cost of the various works, the revenue, the quantities of materials raised each year by the several dredgers since 1844, and the tonnage of vessels entering the port, are given in the printed annual accounts of the trustees.[1]

The River Tyne.

A Paper on the River Tyne was read by the late Mr. W. A. Brooks at the Institution in 1867[2]; but this Paper referred almost exclusively to the original condition of the river, and the early attempts to increase its depth by means of projecting groynes, subsequently joined by longitudinal training-walls, for regulating the width of the channel, carried out between 1843 and 1858, when Mr. Brooks was engineer of the river. These works, aided by the dredging of 1,866,000 cubic yards of materials from the river along the 10½ miles between Newcastle and the sea, between 1838 and 1860, had done away with the fall of the high-water line of about 8 inches from the sea to Newcastle, and had lowered the low-water line at Newcastle about 16 inches, thereby increasing the tidal range there by 2 feet; whilst the minimum available depth in the channel had been increased from 13½ feet to 18 feet at high water of spring-tides. A Royal Commission, however, after a long investigation, reported in 1855, that "very little change had, upon the whole, taken place during a period of upwards of forty years, in the actual navigable capabilities of the river." The navigable channel in 1860 was very winding between the shoals; and the depth over the bar at the mouth was only 6 feet at low water, and 21 feet at high water of spring-tides.

River Clyde," Glasgow, 1885; "On the Improvement of the Clyde above Port Glasgow," Proceedings of the Institution of Mechanical Engineers, 1887, pp. 402 to 408; "The River Clyde," Transactions of the Institution of Naval Architects, 1889, p. 20; Transactions of the American Society of Civil Engineers, 1893, vol. xxix. p. 128, and Plates 1 to 3; and "The Engineering Improvement of the River Clyde," *The Engineering Review*, Nov. and Dec. 1894, and Jan. 1895.

[1] Information about the improvement of the River Clyde is also given in the following publications: "Glasgow et La Clyde," L. Simonin, *La Nouvelle Revue*, Nov. 1880; "On the Dredging of the Lower Estuary of the Clyde," C. A. Stevenson, Proceedings of the Institution of Mechanical Engineers, 1887, pp. 386 to 401, and Plates 75 to 79; "Les Ports de la Mersey et de la Clyde," Baron Quinette de Rochemont, Annales des Ponts et Chaussées, 1892 (2), p. 169, and Plates 25 to 27; and "Rivers and Canals," L. F. Vernon-Harcourt, 2nd edition, 1895, vol. i. pp. 252 to 258, and Plate 8, Figs. 7 and 8.

[2] "Memoir on the River Tyne," W. A. Brooks, Minutes of Proceedings Inst. C.E., vol. xxvi. p. 398.

In 1861, a comprehensive scheme, proposed by the late Mr. J. F. Ure, for the improvement of the river, mainly by extensive dredging operations, was approved; and since that period dredging has been carried on continuously by not less than five, and generally by six bucket-ladder dredgers, discharging into hopper-barges which are conveyed out to sea, and deposit the dredged materials in a depth of 20 fathoms, 3 miles from the mouth of the river. Between 1861 and 1894, 61,363,000 cubic yards of material have been dredged from the bed of the river and from the docks, affording a depth of 20 feet at low water of spring-tides up to Newcastle, and of 18 feet for 3 miles above. The dredging is being continued for maintaining the depth already attained, and for extending the deepening of the river up to Hedwin Streams, $8\frac{3}{4}$ miles above Newcastle.

The river has also been improved for navigation by regulating its width and by the removal of bends. The width of the contracted channel at the "Narrows," near the mouth, has been increased from 400 feet to 700 feet. By the removal of Whitehill Point, opposite South Shields, the channel has been widened 300 feet; and the rocky obstructive projection of Bill Point has been cut back 400 feet by the removal of 2,000,000 tons of rock and clay, 380,000 tons of rock having been blasted under water by dynamite. The waterway has been enlarged at Newcastle by the substitution, in 1876, of a swing-bridge with two central opening spans of 104 feet, and two side openings, respectively $92\frac{1}{2}$ feet and $64\frac{1}{2}$ feet in width, for the old Newcastle Bridge with its restricted openings and numerous wide piers. Above Newcastle, also, the river has been regulated and straightened, a straight cut at Blaydon having shortened the channel by $\frac{3}{4}$ mile.

Piers were commenced in 1856, starting from the shore on each side of the mouth of the Tyne, for protecting the entrance to the river, forming a harbour of refuge, and facilitating the removal of the bar by dredging. These piers, or breakwaters, formed of a low rubble mound protected on the sea side by concrete blocks, and surmounted by a superstructure, founded between 7 feet and 36 feet below low water and composed of concrete hearting faced with masonry,[1] converge towards their extremities, leaving an opening between their pierheads, 1,300 feet in width, so as to allow of the free influx of the flood-tide up the river, and the free discharge of the ebb-tide to the sea. The north pier is 3,059 feet, and the south pier 5,317 feet long; they terminate in a depth

[1] Minutes of Proceedings Inst. C.E., vol. lxxxvii. p. 148, and Plate 8.

of about 35 feet at low water of spring-tides; and the bar has been dredged away under their shelter. The piers were slowly extended on account of the great difficulty experienced in constructing the outer portions, owing to the extreme violence of the seas to which they are exposed; and they were also occasionally retarded by financial causes, and were only completed about two years ago. The erection of a lighthouse on the outer end of each pier will be completed during 1895. On the retirement of Mr. Ure, in 1870, from the superintendence of the works, Mr. P. J. Messent, the executive engineer on the pier works, became engineer to the Commissioners for the whole of the works.

These improvements have raised the Tyne ports to the third place amongst the seaports of the United Kingdom; and many vessels of between 2,000 tons and 4,000 tons enter the river. The range of spring-tides at Newcastle is now 9 inches greater than at the mouth; whilst the low-water line has been lowered 3 feet at Newcastle since 1860, and considerably more higher up the river. The interval between high water at Shields and at Newcastle has been reduced, since 1860, from one hour three minutes to twelve minutes; and between Newcastle and Newburn, 7 miles higher up, the interval has been reduced from twenty-nine minutes to eight minutes. Land floods pass so freely down the deepened river that the riparian lands and the quays between Wylam and Newcastle are no longer inundated periodically. When the dredging in the upper part of the river is completed, the tidal capacity of the river will have been increased by about 20,000,000 cubic yards.

The Northumberland Dock, alongside the north bank of the river, opposite Jarrow Slake, was commenced by the Commissioners in 1853, opened in 1857, and subsequently enlarged; and the Albert Edward Dock of 24 acres, authorised in 1872, was opened in 1884, and is situated on the north bank of the river opposite South Shields; and both these docks are approached from the river through entrance locks. The Commissioners also converted a portion of Jarrow Slake into timber ponds in 1874, with an area of 89 acres. A description of the mode of construction of the Tyne piers, illustrated by sections, was given by Mr. Messent, in the discussion on a group of Papers on "Concrete as applied in the Construction of Harbours," at the Institution, in 1886;[1] and an account of the various improvement works carried out on the

[1] Minutes of Proceedings Inst. C.E., vol. lxxxvii. p. 148.

Tyne, with a plan and section of the river, was printed by Mr. Messent in 1888;[1] and a book on the general history of the Tyne and its improvements was published in 1880.[2]

The Tower Bridge.

The growth of London eastwards along both banks of the Thames has rendered the want of communication across the river below London Bridge increasingly felt, since the first attempt to connect the two shores without interfering with the navigation was made by the construction of the Thames Tunnel in 1825–43. After numerous schemes had been proposed from time to time for crossing the river without hindering the access to the wharves up to London Bridge, by means of a tunnel, a high-level bridge, and an opening bridge, the design of a bridge with a double bascule for the central span, raised on each side against high towers built on the piers, submitted by the late Sir Horace Jones in 1878, was authorised in a modified form in 1885, being the result of a joint design with Mr. J. Wolfe Barry, C.B., Vice-President Inst. C.E., who became sole engineer for the bridge on the death of Sir Horace Jones in 1887, when the foundations for the piers were not far advanced.

The bridge crosses the Thames just below the Tower, where the width of the river between the abutments is 880 feet, and is divided by the two piers, 70 feet broad, into three openings, the two side spans being 270 feet, and the central opening span 200 feet.[3] The roadway of the two fixed spans is suspended from braced chains in two segments, passing over the high towers of the central span and the low towers of the abutments on rollers to provide for expansion and contraction and variations in load. The two chains are connected by ties under the footways over the central span, and are anchored at their shore ends by land ties to large anchorage blocks built underground. The roadway across the central span is carried by two bascules, or balanced cantilevers, each extending out 100 feet from its pier, and meeting in the centre of the span,

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[1] "River Tyne Improvement, Description by Mr. P. J. Messent, C.E., of Works Completed and in Progress by the Tyne Improvement Commissioners, with Chart and Section of the River Tyne from the Sea to Wylam, December, 1888"; and, "Description of the Improvement of the River Tyne," Transactions of the Institution of Naval Architects, 1888, p. 122.

[2] "The River Tyne, its History and Resources," James Guthrie, Newcastle-upon-Tyne, 1880; and a short description of the work is given in "Rivers and Canals," L. F. Vernon-Harcourt, 2nd edition, 1895, vol. i. pp. 213 and 258–264, and Plate 8, Figs. 1 to 3.

[3] Minutes of Proceedings Inst. C.E., vol. cxiii. Plate 4, Fig. 1.

providing a headway of 29½ feet above Trinity high-water for up-river traffic, being the same as under the central arch of London Bridge. Each bascule, carried by four longitudinal girders 13½ feet apart, can revolve into an upright position on a horizontal solid steel pivot, 1 foot 9 inches in diameter, placed 12¾ feet back from the face of the pier, and resting on live rollers. The bascule is counterpoised on the other side of the pivot by a tail-end, 49½ feet long, weighted at its end by about 290 tons of lead and 60 tons of cast-iron carried in a ballast-box, so that each bascule, though weighing altogether 1,200 tons, is readily raised and lowered by revolving pinions driven by hydraulic machinery, working in the teeth on the circumference of quadrants fastened on the tail-end of each of the outside girders. The bascules when raised leave a clear opening of 200 feet, with a headway at high water of 140 feet to the underside of the two high-level fixed footways, supported by the towers, which afford a passage for pedestrians when the bridge is open. The footways are carried by cantilevers projecting from each tower, supporting central lattice-girders of 120 feet span.

The high towers on the river piers shelter the bascules from wind when raised, carry the suspension-chains, support the high-level footways, and also give access to them by means of hydraulic lifts and stairs, and provide rooms and stores in connection with the working of the bridge. Four plate-steel octagonal pillars, connected by horizontal girders and diagonal bracing, form the skeleton of each tower, and bear all the strains occasioned by the roadways. These steel skeletons have been encased in masonry and brickwork, which, besides affording the architectural features rendered necessary by the conspicuous position of the bridge and its proximity to the Tower, protect the framework from corrosion and extremes of temperature, and shelter the machinery inside and the approaches to the high-level footways.

Notwithstanding the reduction in the weight of the towers by the introduction of steel in place of towers built wholly of masonry, the bascules, with the high towers, machinery and fixed roadways, impose a maximum weight of nearly 70,000 tons upon the piers, so that the foundations had to be made 100 feet in width and 204½ feet long to the ends of the cutwaters, in order that the load on the London clay might not exceed 4 tons on the square foot, at a depth of about 26 feet below the surface. Each pier, resting on a concrete foundation, and built of gault brickwork set in cement and faced with granite, provides four accumulator chambers, and two engine-houses for the hydraulic

engines by which the bascules are raised, as well as the large recess, in the form of a quadrant of a cylinder, into which the tail-end of the bascule dips on opening the bridge, and over which the roadway is carried on fixed girders. The hydraulic power for working the bascules and the lifts in the towers, is stored up by the accumulators in the piers and by two other accumulators near the Surrey approach to the bridge, the pressure being supplied by steam-engines and pumps situated under the southern approach.

The piers were founded by the aid of a group of twelve wrought-iron caissons, strutted with wood, sunk into the bed of the river, the first caisson having been commenced in September 1886. Owing to delays, on account of a clear waterway of 160 feet having to be left for navigation, and the difficulties of the site in respect of access, the piers were not completed, up to 4 feet above high water, till January 1890. The construction of these piers, with their foundations, has been fully described by Mr. G. E. W. Cruttwell, M. Inst. C.E., the resident engineer, in a Paper on "The Foundations of the River-Piers of the Tower Bridge."[1]

On the completion of the piers, access was obtained to them by temporary staging from the shore on each side; the steel framework of the towers was then erected, with the three landings or floors; and from the top of the third landing, the cantilevers of the high-level footways were built out, with their central girders which were joined in the centre of the span, without the aid of any scaffolding below them. The low towers on the abutments were built in the meantime, and the fixed roadways and suspension chains erected on the temporary staging; and the chains were connected with the central and land ties. The girders of the bascules were built in a vertical position; and when extending 40 feet beyond the line of piers, the working parts were adjusted and tested, without encroaching on the clear waterway of 160 feet which had to be maintained. These girders were then completed; the central towers encased in stone were raised to their full height, with a fourth landing above the high-level footways; over which the high-pitched roofs, with their steel ribs, were erected.

Approach roadways on brick arches faced with stone, provide access to the bridge from the thoroughfares on both sides of the river. The roadway on the fixed spans is 35 feet in width, with footways on each side 12¼ feet wide; and these widths are reduced along the bascules to 32 feet and 8½ feet respectively; whilst the high-

[1] Minutes of Proceedings Inst. C.E., vol. cxiii. p. 117, and Plate 4.

level footways are each 12 feet wide. The roadway on the bridge rises to the centre with a gradient of 1 in 75; and the gradients on the approaches are 1 in 60 and 1 in 40. The bridge was opened for traffic in July 1894, about eight years from the commencement of the works; and the cost of the structure, with its approaches and land, which amounted to upwards of £1,000,000, was entirely defrayed by the Corporation of London. The machinery of the opening span is controlled by levers on the piers, provided with interlocking apparatus; and the bascules can be raised in one minute and a half, when the bolts locking them together in the centre have been withdrawn.

The works have been described and illustrated in "The Tower Bridge," by J. E. Tuit, mainly reprinted from articles in *The Engineer*, and published simultaneously with the opening of the bridge in 1894; and a shorter and more popular account was written by Mr. J. Wolfe Barry, for a lecture delivered in 1892,[1] and printed for private circulation, extracts from which are contained in the "History of the Tower Bridge," by Charles Welch, published by desire of the Corporation of London, towards the close of 1894.

[1] "The Tower Bridge: a Lecture." J. W. Barry, London, 1894.

OBITUARY.

ROBERT CRICHTON was born at Glasgow on the 21st of December, 1847. His father, Mr. David Crichton, was cashier at the Hurlet and Campsie Alum Works, of which Sir James King is now the principal. His grandfather, James Crichton, was a well-known philosophical instrument maker, established in Glasgow for about half a century. This James Crichton when a young man of promise was taken into the family of Dr. Anderson, Professor of Natural Philosophy in the University, for whom he made models and instruments and from whom he gained scientific knowledge. He invented and constructed, in the course of his long business career, instruments excellent in their day, including astronomical apparatus, dipping-needles, hydrostatic balances, weather-gauges, thermometers, and index-locks.

Robert Crichton was educated at the High School, and became in 1863 a pupil of Mr. Robert Strathearn, civil and mining engineer. Having served a pupilage of four years, he was for two years assistant on the engineering staff of the Glasgow and South Western Railway. Then from 1869 to 1873 he was with Messrs. Kyle and Frew, Messrs. Ronald Johnstone and Rankine, and Mr. William Crouch, all of Glasgow. In 1873 he was again on the engineering staff of the Glasgow and South Western Railway, remaining until 1875, when he entered the service of the London and North Western Railway Company. At first he acted as resident assistant engineer of the West Cumberland District under Mr. S. B. Worthington. In August, 1883, the lines between Carlisle and Ingleton were added to this district, which in the following year was extended to Euxton Junction, when Preston became Mr. Crichton's head-quarters. In 1886 he was promoted to the post of assistant divisional engineer of the same extended district, and on the death of Mr. J. G. Brickenden,[1] in November, 1887, he was appointed divisional engineer of the Northern Division of the London and North Western Railway. This post he held during the remainder of his life.

While photographing a building on the railway at the end of December, 1894, Mr. Crichton slipped on stepping from some loose bricks and grazed his leg. Blood-poisoning seems to have

[1] Minutes of Proceedings Inst. C.E., vol. xcii. p. 382.

developed from a trifling wound and within three weeks he died at his house in Lancaster, on the 17th of January, 1895, at the age of forty-seven years. Mr. Crichton was a careful, conscientious worker, with a considerable amount of Scottish tenacity of purpose when he believed himself to be in the right. He had acquired much sound practical knowledge, for which he was distinguished rather than for scientific attainments. He was the inventor of improvements in diamond railway-crossings. Mr. Crichton was elected a Member on the 3rd of February, 1891.

JOSEPH MITCHELL, of Bolton Hall, near Rotherham, was the eldest son of the late Joseph Mitchell, of Swaithe Hall, near Barnsley, by Anna, daughter of the late Mr. Binns of Wentworth. He was born on the 7th of September, 1840, at Worsborough Dale, near Barnsley. At the commencement of his career he was engaged with his father in various collieries in Worsborough Dale, also in the iron works and foundry called Mitchell's Worsborough Dale Foundry. In time he assumed the control of the latter establishment, then the leading one in the district, supplying the neighbouring collieries with engines, boilers, &c., and turning out most of the bridges for the old South Yorkshire Railway. During this time a lamentable explosion occurred at Edmund's Main Colliery, in the re-opening of which it fell to him to take a leading part. Again, after the explosion at the Swaithe Main Colliery in 1875, he was called in to take charge of the re-opening of the pit, and to put the same into working order.

About the year 1871 his father formed the idea of sinking the Mitchell Main Colliery on the dip of the Swaithe Main Colliery, and the sinking was commenced after a considerable amount of time and money had been expended in combating with water. He was again called in to complete the sinking, which he successfully accomplished in 1875, the quantity of water to be dealt with averaging 2,700 gallons per minute. During the drought which occurred about this time, when the whole district of Worsborough Dale was very short of water, Mr. Mitchell mooted the question of bringing water from Barnsley to the district, and this, with the help of others, he successfully accomplished. His connection with the Mitchell Main Colliery brought to his knowledge the scarcity of water in the Wombwell district and induced him to apply, along with others, to Parliament to be allowed to use, in supplying the district of Wombwell, the powers obtained by the Wakefield

Corporation for acquiring water from the Oaks Rock in the Wombwell district. The application made in 1879 was not successful, but in 1880 powers were granted to the Dearne Valley Water Company. The scheme as then laid before Parliament he successfully carried through; the works were opened in February, 1884, and by their means water is supplied to over 40,000 inhabitants at a total outlay of some £32,000.

In the various undertakings in the district necessitating application to Parliament Mr. Mitchell's advice was frequently sought, and his services were requisitioned in many instances as umpire and arbitrator, and for the valuation of properties in America and elsewhere. Some two years before his death he arranged to take about 2,500 acres of the Barnsley Bed of Coal at Grimesthorpe, near Barnsley, from Mr. F. J. S. Foljambe, and the sinking operations were commenced on the 8th of October, 1894. The plans for and the method of conducting the works were prepared and left ready for carrying on the sinking operations.

In 1879 Mr. Mitchell was elected Secretary of the Midland Institute of Mining, Civil and Mechanical Engineers. In that year the Council met to consider the evidence to be given before the Royal Commission on Accidents in Mines, and he was appointed one of the deputation to attend and give evidence. In 1877, 1878 and 1881 he contributed Papers on "Outbursts of Gas at Mitchell Main Colliery,"[1] upon which interesting discussions took place. During his tenure of office as Secretary important experiments on safety-lamps were carried out, and reports issued upon the various types and their relative efficiency.[2] In these experiments he took an active part. By his energy and perseverance the status of the Institute was revived, and its position as the leading Mining Institute of the Yorkshire Coal-field was assured. From 1890 to 1892 he served the office of President. He delivered an inaugural address[3] on the 16th of December, 1890, in which, amongst other matters, he dealt with the Eight Hours Question as it affected the South and West Yorkshire miners.

Mr. Mitchell took great interest in the federation of the Mining Institutes of England. During his busy life he also found time to attend to local matters, and in no place will his advice be more missed than on the Wombwell District Board. It was through his exertions that the present successful sewage scheme was initiated,

[1] Trans. Midland Inst. Mining Engs., vol. vi. pp. 275, 276; vol. vii. p. 212.
[2] *Ibid*, vol. ix. pp. 98, 266; vol. x. p. 83. [3] *Ibid*, vol. xii. p. 148.

and the gasworks were acquired for the benefit of the township. He was a member for seventeen years, and chairman for fourteen years consecutively, and it was only through ill-health that he resigned in 1894. He died, from heart disease, at his residence, Bolton Hall, Rotherham, on the 18th of April, 1895. His character and business abilities are well summed up in the opinion expressed by a local paper:—

"He will be sorely missed not merely by the members of his own family and by those who were numbered among his friends, but by his workmen and the public generally. His manners may have appeared to those who did not know him a trifle brusque, but while he held his own opinions tenaciously and expressed them freely, he was ready to accord to those who differed from him the same freedom which he claimed for himself, and to those who had frequent occasion to come in contact with him he was always genial and obliging."

Mr. Mitchell was married in 1862 to Kate, daughter of Mr. George Howe, of Boulogne-sur-Mer, who survives him. He was an active member and Past Master of the Lodge Friendly "1513" of the Ancient Order of Freemasons. He was one of the Board of Governors of the Yorkshire College during his term of office as President of the Midland Institute, and was one of the examiners for colliery managers' certificates for the Yorkshire and Lincolnshire district at the time of his death. In 1892 he was appointed a Justice of the Peace for the West Riding of Yorkshire. He was elected an Associate on the 6th of April, 1875, and was transferred to the class of Member on the 25th of October, 1887.

JAMES PRICE, M.A.I., born on the 18th of January, 1831, at Monkstown, Co. Dublin, was the second son of Mr. James Price, of Newtown Park, Monkstown. After being educated at Trinity College, Dublin, where he obtained the diploma of the Engineering School in 1850, and took the degree of Bachelor of Arts in 1851, he received an appointment on the staff of the General Valuation of Ireland, and subsequently was employed by Mr. James Barton, of Dundalk, as general assistant. From 1855 to 1857 he was engaged, for Mr. Barton, as Resident Engineer in responsible charge of the construction of the Banbridge Junction Railway. He then acted for eighteen months as engineer on the Wicklow harbour improvements. In 1859–60 he was Resident Engineer on the construction of the Cootehill and Ballybay line, and was then engaged for two years in charge of the permanent way and works of the Dublin and Belfast Junction Railway.

At the end of 1862 Mr. Price was appointed Engineer-in-Chief of the Midland Great Western Railway of Ireland, with which office was shortly afterwards combined the charge of the Royal Canal. These posts he held until May, 1877. While in the employment of the Midland Great Western Railway Company he constructed the Spencer Docks, Dublin, for which the degree of Master of Engineering (without fee) was conferred upon him by Trinity College, Dublin, and a purse of money was presented to him by the railway company. In conjunction with Mr. R. Price-Williams, he very successfully worked up the claims of the Midland Great Western Railway, and of several other Irish Railway Companies, against the Postal Telegraph Department on the occasion of the purchase of telegraphs by the Government.

Mr. Price was one of the three engineers selected by the Corporation of the City of Dublin to report jointly upon the purification of the river Liffey—which was presented by Messrs. Cotton, Price and Palles in September 1874.

From 1877 until his death Mr. Price practised on his own account in Dublin. During that time he carried out the Galway New Dock Works and the Lough Erne Drainage, a description of which was presented to the Institution in 1890 by his eldest son.[1] He acted also as Consulting Engineer for the Cork and Macroom line, and was engaged by the Waterford and Limerick Railway and other companies in various parliamentary cases. Mr. Price was always a strong advocate of light railways of the full gauge as against narrow-gauge lines for Ireland; and he was employed by Government as commissioner to hold inquiries and to report on various light railway and tramway schemes in the north and north-west of Ireland. In 1887 he acted as deputy Professor of Engineering in Trinity College, Dublin, for Mr. Robert Crawford, invalided. In the following year he gave evidence before the Government commission with reference to the Barrow Drainage, on behalf of the riparian owners of the lower Barrow and the Barrow Navigation Company. The scheme he then proposed consisted of a combination of sluices and storage reaches formed by embankments with back drains to allow land water to enter the main channel below the sluices. He designed a form of floating swing-bridge—two of which he constructed at the Spencer Dock—particularly for situations where a good foundation was difficult to be obtained, and was the first to introduce the bascule into Ireland, in lieu of a drawbridge over the river Shannon, at

[1] Minutes of Proceedings Inst. C.E., vol. ci. p. 73.

Drumsna, Co. Leitrim, on a branch of the Midland Great Western Railway. In the present year he was elected President of the Institution of Civil Engineers of Ireland.

Mr. Price was strong and active up to a week before his death. An attack of influenza, followed by pneumonia, proved fatal on the 4th of April, 1895. He was elected a Member of the Institution on the 1st of March, 1870. In the following year he presented to the Institution a Paper, "On the Testing of Rails,"[1] for which he was awarded a Telford Medal and a Telford Premium. In 1879 he contributed a second Paper, entitled "Movable Bridges,"[2] for which he again received a Telford Premium. He married in 1855 Frances Alicia, daughter of Dr. Peebles, of Dublin. Mr. Price was a man of large-hearted sympathy, and gave much time and energy to works of benevolence. He was a member of the General Synod of the Church of Ireland, and was widely esteemed and respected.

ALFRED GEORGE WOODWARD REID, C.M.G., born on the 26th of October, 1849, was educated at King's College, London. In 1870 he was articled to Messrs. Armstrong and Mitchell of London, Civil Engineers, and by them employed on the Isle of Man Railway and on the Chester and Holyhead line. In August, 1871, he obtained by open competition an appointment as an Assistant Engineer in the Public Works Department of the Government of India. During the first five years of his service he was employed on military works in the Gwalior, Lucknow, Dugshai, and Chakrata Road Divisions, and established a reputation as a practical engineer with considerable technical knowledge.

In February, 1877, Mr. Reid was temporarily transferred to the Bombay Presidency for employment on Famine Relief Works. He was subsequently thanked by the Government of Bombay for the services he then rendered. In April, 1878, he was posted to the Punjab Irrigation Branch, and for nearly four years he acted as subdivisional officer in charge of the headworks of the Sirhind Canal, displaying marked ability and zeal in the carrying out of those duties. He was then appointed to the executive charge of the new third division of the Sirhind Canal, including the headworks and main line, and was engaged for three years in designing and completing the distributary system of that section of the canal.

In July, 1885, Mr. Reid proceeded on furlough for two years.

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[1] Minutes of Proceedings Inst. C.E., vol. xxxii. p. 192.

[2] *Ibid*, vol. lvii. p. 1.

This involved, however, no interruption to his professional labours, for, on arriving in Egypt, he accepted an appointment under the Egyptian Government, to which, on the expiration of his furlough, his services were lent for a further period of three years. During those five years Mr. Reid had sole executive charge of the important and difficult works designed by Lieut.-Colonel J. H. Western, R.E., C.M.G.,—under whom he had served on the Sirhind Canal—for the strengthening and practical reconstruction of the barrage at the head of the Rosetta and Damietta branches of the Nile. These works were fully described in a Paper by Mr. William Willcocks, read before the Institution in February, 1887.[1] Mr. Reid's able services in the development of Egyptian irrigation were highly commended by Colonel Sir Colin Scott-Moncrieff, R.E., K.C.M.G.; he was appointed a Commander of the Imperial Order (Turkish) of the Osmanieh in 1889, and in May, 1890, he was created a Companion of the Order of St. Michael and St. George.

On the completion of the barrage Mr. Reid returned to India—in July, 1890—and was placed in charge of the Ludhiana Division of the Sirhind Canal. In April, 1893, he acted as Superintending Engineer of the Cis-Sutlej Circle, but his health soon afterwards failed and he proceeded to Simla, where he was placed on special duty under the Chief Engineer of the Irrigation Branch. The change to the hills effected only a partial restoration of his health, which early in 1894 broke down entirely. After rallying from a severe and critical illness he left for Europe on the 2nd of May. In England his health somewhat improved and strong hopes of his gradual recovery were entertained. These, however, were unhappily doomed to disappointment. Alarming symptoms showed themselves and the end came suddenly on the last day of September.

As an Engineer Mr. Reid's qualifications were undoubtedly high; his knowledge of the theoretical and practical sides of the profession was wide and deep and was kept up to date by constant reading and travel. He was a shrewd and close observer, with great power of organization, possessed of strong nerve and sound judgment. As an officer he was upright and conscientious, and was deservedly esteemed for his ability and zeal, for his just and equable disposition, and for his patience in instructing and readiness to encourage all who served under him. As a man he will long be remembered for a high sense of honour, unfailing cheerfulness and kindness of heart. Mr. Reid was elected a Member on the 3rd of March, 1891.

[1] Minutes of Proceedings Inst. C.E., vol. lxxxviii. p. 300, and vol. xc. p. 240.

EDWARD REYNOLDS, born in London on the 7th of October 1825, was the son of the late Mr. William James Reynolds. Most of his boyhood was spent in Herefordshire at school. At an early age his aptitude for mechanics was remarkable; out of fragments of toys he put together—long before he had seen a steam-engine, and solely with the aid of rude diagrams in a book for boys—a small model of a section of a beam-engine, the movable parts of which were properly adjusted. About the year 1839 he was sent to King's College, London, where he became a student in the engineering department. He was apprenticed in February, 1844, to the late Mr. William Bridges Adams, of the Fairfield Works, Bow, with whom he remained for two years. He was then employed from 1846 to 1850 as Chief Draughtsman in the Locomotive Department of the Eastern Counties Railway. During that time slab frames were substituted in the locomotives for the old bar frames, a change rendered necessary by the alteration of gauge from 5 feet to 4 feet 8½ inches. From 1850 to 1852 Mr. Reynolds was engaged in designing Warren-girder bridges and bridges generally. He was then appointed Chief Engineer to the Butterley Iron Company, at whose works he remained for eight years. During that period he remodelled a large portion of the plant, several of the engines and locomotives designed by him for the Company being still at work. In September, 1860, he entered into partnership with Mr. (now Sir Frederick) Bramwell, a connection which lasted until the early part of 1863. During that time he acted as Consulting Engineer to the Butterley Iron Company.

Mr. Reynolds then became engineer to Messrs. Naylor, Vickers and Co. of Millsands, Sheffield, and was engaged in the construction of the River Don Works. In 1872, nine years later, he was appointed a managing director of the Company, which had become Vickers, Sons and Co., Limited, and retained that position until his death. Among the more noticeable plants designed by Mr. Reynolds at those works are the large forging-presses, the construction of which was commenced in 1882. He then introduced the long stroke type of forging-press, the ram working on the spherical end of a guided inverted T-shaped cross-head carrying the forging face; the slack before the actual pressing being taken up by water from a source at a lower pressure. This system, which he had adopted some time before for general hydraulic work, possessed the advantage that smaller pumping engines might be employed. Mr. Reynolds was a man of retiring

disposition, who generally disliked taking part in public matters. In 1894 he joined the boards of the Elmore Copper and Wire Companies and took an active interest in their management and in the technicalities of their manufacture. During his long engineering life he had the good fortune to be concerned in or to see the beginning of many manufactures and inventions, a notable instance being the experiment made by Captain Blakely, R.A., at the Butterley Iron Works in connection with the system of reinforcing guns with hoops in initial tension. Mr. Reynolds' memory was remarkably good, and his extensive and minute knowledge, great originality, insight, and largeness of view in business relations, were the secret of his success. In addition, his self-reliance and unfaltering moral courage contributed much to his influence on men individually and collectively.

For some time previous to his death Mr. Reynolds' colleagues and others had noticed signs of failing health, these symptoms rapidly developing during the latter part of 1894. Although he suffered for some months from cardiac asthma he remained actively at work until the 5th of January, when a chill he had contracted hastened his end, which took place on the 12th of January, 1895. Mr. Reynolds was a member of the Institution of Mechanical Engineers, the Institution of Naval Architects, the Society of Arts, the Society of Engineers, and the North East Coast Institution of Engineers and Shipbuilders. He was elected a Member of this Institution on the 5th of February, 1889.

ALFRED THOMAS COOKE was born on the 14th of September, 1819. He served a pupilage to Sir Marc Isambard Brunel,[1] during the construction of the Thames Tunnel, and was afterwards apprenticed to Mr. Joel Spiller,[2] at whose works at Battersea he was engaged on the construction of the engines for the first steamboats which ran on the Thames.

Mr. Cooke was next employed for three years as a draughtsman at the Horsley Ironworks, Tipton. He then entered the service of the Honourable East India Company as a marine engineer. After nearly six years at Bombay and afloat, he was appointed by Messrs. Miller,[3] Ravenhill[4] & Company of Blackwall, to the

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[1] Minutes of Proceedings Inst. C.E., vol. x. p. 78.
[2] *Ibid*, vol. xxxviii. p. 296.
[3] *Ibid*, vol. xx. p. 149.
[4] *Ibid*, vol. lxxxix. p. 495.

service of the Austrian Lloyd Steam Navigation Company. For four years he was employed between Venice and Trieste, at Alexandria and at Constantinople, in inspecting machinery, both during construction and while working. While in Venice he assisted in the design and construction of some bridges for Baron Rothschild.

From 1854 to 1856 Mr. Cooke acted as Resident Engineer in charge of the engineering work in connection with the construction of the Crystal Palace at Sydenham. He was then engaged by Mr. Henry Grissell to construct a patent dry dock slip at Cronstadt, and on other important works in various parts of the world, in connection with lighthouses, bridges and railways. In 1867 Mr. Cooke designed and constructed the Ceará Waterworks in North Brazil. On the completion of those works he returned to England, and, after fulfilling various minor engagements, went to Ryde and assisted in the construction of the tunnel under the Esplanade and of the Railway Pier. He was then retained by the Joint Railway Company in the Isle of Wight as Resident Engineer, which appointment he held until his retirement in 1894.

Mr. Cooke died at Ryde on the 15th of April, 1895, from paralysis and cerebral hæmorrhage. He was elected an Associate on the 1st of April, 1856, and was subsequently transferred to the class of Associate Members.

HARRY JONES HARMAN, son of Mr. Harry William Harman, of the Fairbairn Engineering Company, was born in Manchester on the 29th of July, 1846. After an apprenticeship at the Fairbairn Works he was in 1871 appointed an Assistant Engineer in the service of the Khedive of Egypt, in which capacity he superintended the erection of sugar plant in that country. On completing that work he was engaged by the late Duke of Sutherland for four years in designing and superintending the erection of saw mills, engineering shops and other works on the Scotch estates of that nobleman.

Mr. Harman next acted as Chief Engineer to the Scottish Boiler Insurance Company, Manchester, for four years, after which he practised in that city, remaining, however, Consulting Engineer to the Company until 1886. In that year he was appointed chief of the engineering staff of Messrs. Rownson, Drew & Company, with which firm and its successors, Messrs. Drew-Bear, Perks & Company, he remained until his death from consumption on the 18th

of February, 1895. Mr. Harman was elected an Associate on the 6th of February, 1877, and was subsequently placed in the class of Associate Member.

FREDERICK JORGENSEN was born in Copenhagen on the 9th of August, 1831. After graduating at the Polytechnic School in that city, he served an apprenticeship from 1847 to 1852 in the Royal Danish Naval Engineers' Establishment at Copenhagen. He was then from 1853 to 1857 with Messrs. Maudslay, Sons and Field, Lambeth, as a fitter and erector, and was subsequently employed for twelve months as an engineer afloat by the Genoese Transatlantic Company.

In December, 1858, Mr. Jorgensen entered the service of the Austro-Hungarian Lloyd Steam Navigation Company, and for the next sixteen years was engaged partly in the construction department at the Company's Arsenal in Trieste and partly as Chief Engineer on board its mail-boats. In 1874 he was appointed Engineer-in-Chief and Inspector of Machinery at the Company's Constantinople Station, which position he held until his death. Since 1883 he acted also as Consulting Engineer to the Bosphorus Steam Navigation Company and as Surveyor and Technical Referee, in matters relating to machinery and iron vessels, to H.B.M.'s Supreme Consular Court and to the British Consulate, at Constantinople.

At the beginning of 1895 Mr. Jorgensen was advised to seek rest and change of air. He took a sea voyage to Trieste, expecting to be away from home only a few weeks. At Trieste, however, a stroke of paralysis of the brain supervened and proved fatal on the 28th of February. Mr. Jorgensen was an able engineer, while his kind manner and readiness to help others made him generally respected and esteemed. He was elected an Associate Member on the 4th of March, 1890.

WILLIAM MACGLASHAN, B.Sc., son of the late Mr. Thomas MacGlashan, of Sauchie, Dupplin, Perthshire, was born on the 26th of July, 1865, and was educated at St. Andrews and at the University of Edinburgh, where he took the degree of Bachelor of Science. In 1882 he was apprenticed for four years to Messrs. Carfrae and Belfrage, civil engineers, of Edinburgh. He then served for twelve months as an assistant to Mr. John Strain on the construction of the Lanarkshire and Ayrshire Railway, and for

eighteen months as an assistant to Messrs. Formans and McCall on Parliamentary work in connection with the Glasgow Central Railway and the West Highland Railway.

In 1888 Mr. MacGlashan proceeded to Singapore as an assistant to Mr. Archibald A. Swan in staking out and in preparing working drawings for 60 miles of the Perak Government Railways. In 1890 he went to Siam and was engaged at the gold mines in Bangtaphan on the design and construction of a combined timber and masonry dam on the Klong Thong (or Gold River), on a hydraulicking scheme at Pa Ron, and on a survey of the Goldfields of Siam Company's lands and roads from the hills to the sea. In connection with the hydraulicking scheme a letter has been received from the medical officer to the company of so interesting a character that an extract is here given. Referring to Mr. MacGlashan, he writes:—

"It was our fortune to be locked up together within a boundless expanse of jungle in the Malay Peninsula for a solid space of fifteen months, and human nature must be made of rare good stuff that wears well under these circumstances. He was sent up by Swan of Singapore to run the levels for a prospective water-course through a piece of very dense jungle. It was one of the pleasantest of pictures to see MacGlashan assemble his little squad of semi-nude Siamese boys in front of his bungalow in the morning and march them away in Indian file, armed with theodolite, staff, chain, jungle knife and drinking bottle. He was always cheerful, and consequently they were always merry. They toiled much and sweated much amid hot and malarious conditions, and fever comes as a natural sequence. There is no better touchstone for human character than fever; the busy man thinks and worries about his business, the selfish man is engrossed with himself, but MacGlashan became more content as his temperature went up."

The work upon which Mr. MacGlashan was engaged in Bangtaphan having been satisfactorily completed, he returned to Singapore and was subsequently appointed to the engineering staff of the Royal Siamese Railways. His promising career was, however, prematurely cut short on the 2nd of January, 1895, his death, which was most unexpected, being due to apoplectic fits. Mr. MacGlashan was elected an Associate Member on the 1st of December, 1891.

JAMES ARCHIBALD MAUGHAN was born at Morpeth, Northumberland, on the 11th of June, 1843. He served an apprenticeship from 1860 to 1865 to Mr. R. Simpson, engineer of the Towneley and Stella Company's collieries at Blaydon-on-Tyne, and was then for eight years in resident charge of collieries under Mr. J. B. Simpson.

In 1876 Mr. Maughan was appointed agent and manager of the Nerbudda Coal and Iron Company's works at Garrawarra in the Central Provinces of India, which post he held for eleven years, being frequently consulted during that time on mining matters by the Indian Government. At the end of 1887 he was appointed by the Government general manager of the Umaria and Warora Collieries and of the 40 miles of railway from Kutni to Umaria. The latter post he held until the Kutni-Umaria line was taken over by the Bengal-Nagpur Railway Company. The position of manager of the Umaria and Warora Collieries he filled until his death on the 20th of December, 1894, from apoplexy after only a few hours' illness.

Mr. Maughan possessed an intimate knowledge and experience of mining in India, which, coupled with good business capacity and tact, made him an extremely valuable officer. As to his personal characteristics, an old friend writes: "A more conscientious and honourable man never breathed. Hospitable to a degree, tender-hearted and sympathetic in all his dealings and of a simple and guileless nature, he was essentially a man to be liked." Mr. Maughan was elected an Associate Member on the 6th of December, 1887.

JAMES ABBOTT OXLEY, born on the 3rd of July, 1852, commenced his engineering career as a pupil to the late Mr. Robert Davison[1] from 1872 to 1875. He was then engaged for three years under Mr. John Batey, engineer to the Westbury Iron Company, in sinking two shafts through heavily watered strata to win coal. On the completion of that work he was occupied for a short time, under Mr. Henry Tomlinson, on the Frome Waterworks, and was then appointed Resident Engineer to Messrs. Garton & Co., sugar refiners, of Southampton, for whom he designed and erected a new refinery at Battersea.

In August, 1882, Mr. Oxley entered the service of the Cape Government Railway Department, as an Assistant Engineer, and was occupied until October, 1883, on the construction of the first section of the Cradock and Colesberg extension, under the late Mr. T. P. Watson.[2] He then proceeded in January, 1884, to Argentina, to take up the appointment of a District Engineer on the Buenos Ayres Great Southern Railway. In December, 1887,

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[1] Minutes of Proceedings Inst. C.E., vol. lxxxiv. p. 442.
[2] *Ibid*, vol. lxxx. p. 335.

he went over to the Buenos Ayres and Rosario Railway, and was engaged on the construction of the Sunchales and the Santiago del Estero to Tucuman extensions of that line. Before the construction was far advanced, however, he was obliged by family reasons to resign his appointment in 1889.

Beyond an occasional survey for the Argentine Government, Mr. Oxley was from that time not engaged on engineering work until February, 1894, when he went to Beira, East Africa, and thence up country exploiting for gold and arranging the survey of farms for the Mozambique Company. In March, 1895, he was appointed Inspector of Mines at Massikesse, and was engaged in making final arrangements for his second start up country, when he was attacked by sunstroke and died within two hours, at the British Consulate, Beira, on the 21st of that month. Mr. Oxley was elected an Associate Member on the 2nd of December, 1884.

WILLIAM MONRO PEARSE, son of the late Mr. Geddie Pearse, then Engineer to the British Gas Company, was born on the 10th of March, 1840, and was educated at Merchant Taylors' School. He served a pupilage to Messrs. James Simpson & Co., of Pimlico, from September, 1857, to March, 1859, and to Messrs. John Penn & Sons, of Greenwich, from the latter date until March 1862. He was then for some months in the drawing office of the late Mr. John Hodgson Jones,[1] and from February, 1863, was for a short period an Assistant Engineer in the service of the European Gas Company at Hâvre. Having private means he then ceased to follow the profession for some years.

In January, 1875, Mr. Pearse accepted an appointment as an Assistant Engineer to the Commercial Gas Company, and had charge, under the late Mr. Robert Jones,[2] and Mr. H. E. Jones, of the erection of the new works at Poplar. Mr. Pearse remained in the service of the Company—as Inspector of its most important district—until his death, which took place on the 26th of February, 1895, from blood-poisoning resulting from internal hæmorrhage. His constant endeavour was to do thoroughly whatever it fell to his duty to perform, and his disposition being kindly and genial, he made and retained several warm friendships. Mr. Pearse was elected an Associate Member on the 5th of February, 1884.

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[1] Minutes of Proceedings Inst. C.E., vol. cxii. p. 353.
[2] *Ibid*, vol. cxx. p. 356.

ALFRED COVENEY PRIESTLEY, born on the 2nd of December, 1837, was articled in 1853 to Sir Charles Fox,[1] under whom he served for five years at the London Works, Birmingham. He was then appointed an Assistant Engineer on the Cape Government Railways, and from 1858 to 1863 was first in charge of the construction of 16 miles of the Cape Town and Wellington line, and subsequently employed on surveys for extensions.

In 1864 Mr. Priestley, whose services were no longer required by the Colonial Government, returned to England and was engaged for six months as an Assistant Engineer on the Carnarvon and Llanberis Railway. He was next employed from 1865 to 1871 on the construction of the Metropolitan District Railway [2] for the contractors, Messrs. Kelk, Waring Brothers and Lucas, and was then engaged for three years on the Somerset and Dorset and the East London Railways for Messrs. T. and C. Walker, the contractors. In 1874 he entered the service of Messrs. Lucas Brothers, which firm became Messrs. Lucas and Aird in the following year.

Mr. Priestley was for twenty years Chief Engineering Agent in the office of Messrs. Lucas and Aird, and during that period was intimately connected with the large dock, railway and other works, carried out by that firm, among others the Royal Albert Dock, the Tilbury Docks, the Alexandra Dock (Hull), and various extensions of the Midland, Chatham and Dover, and South Eastern Railways. He died on the 16th of February, 1895, from acute bronchitis. Mr. Priestley was elected an Associate on the 1st of December, 1874, and was subsequently placed in the class of Associate Member.

HARRY LAURIE STANNARD, second son of the late Mr. Robert Stannard, was born at Weymouth on the 16th of August, 1859. He was educated at Fullands College, Taunton; but delicacy of constitution led to his being kept much at home during his early years. As a result, his time from 1870 to 1877 was mainly spent on the railway works then being carried out under the supervision of his father, viz., the Devon and Somerset Railway, the Wye Valley Railway, and the Kettering and Manton Railway. These surroundings and his inherited taste for engineering, aided by the constant association with his father (who was an engineer of great experience in railway construction)

[1] Minutes of Proceedings Inst. C.E., vol. xxxix. p. 264.
[2] *Ibid*, vol. lxxxi. p. 1.

gave him, at an unusually early age, an extended practical knowledge of constructive engineering and of the management of men.

In 1877 young Stannard became Assistant Engineer on the works of the Acton and Ealing Railway, and a year later filled the same position on the West Brompton and Putney Bridge Extension of the District Railway. In 1879, his health having given way, he sailed for Australia, where he was occupied for a considerable time in irrigation and estate development. Returning in 1881, he was engaged to represent the contractors for the construction of the Natal and Nova Cruz Railway, North Brazil, where he remained until the completion of the line in 1884. He was one of the engineers sent out, in 1885, by Messrs. Lucas and Aird in charge of the abortive Suakim and Berber Railway. In the following year he again went to Brazil, and carried out an extension of the Natal and Nova Cruz Railway; after which he was for some time engaged on the Ceará Harbour Works, being invalided home, however, before their completion. On his recovery, he was commissioned to survey a line of railway through the territory of the Sultan of Johore.

After returning from Singapore, Mr. Stannard settled in Westminster as a consulting engineer and became interested in various mining projects. At this time he introduced, in conjunction with a colleague—the late Mr. Jennings—an ingenious system for tunnelling in shallow or treacherous ground by means of steel needle bars. The system was used with success in the King's Cross tunnel, the contractor for which subsequently acquired the rights in the patent. In 1894 Mr. Stannard proceeded to Port Beira, East Africa, and was engaged for some months in developing mining properties at Fort Massikesse, Manicaland, where he died from malarial fever on the 31st of December of that year.

Mr. Stannard possessed to a marked extent most of the qualities which go to make successful pioneers—sound practical knowledge, tact in managing men, a buoyant temperament, the power of adapting himself readily to any conceivable circumstances, and ever-resourceful energy. Personally, he was a universal favourite from his kindly tolerant disposition—ever a good comrade and a sincere friend.

Mr. Stannard was the grandson of one of the earliest pioneers of railways, his grandfather—Mr. Robert Stannard, sen.—having had charge of Stephenson's historic work of carrying the Liverpool and Manchester Railway across Chat Moss. Mr. Stannard was at that time engaged in reclaiming the Moss on behalf of its owner, Mr. Roscoe, and was consulted by Stephenson as to the feasibility of

crossing it; and when that route was finally decided on, it was to him that Stephenson entrusted the accomplishment of the famous task.

Mr. Harry Laurie Stannard was elected an Associate Member on the 1st of December, 1885.

JOHN HENRY STRACHAN, born on the 12th of February, 1864, began his engineering career as an apprentice to Messrs. Naylor and Bell of Newcastle-on-Tyne. After remaining four years with that firm, he acted in 1883 and 1884 as a general assistant to his brother, Mr. George R. Strachan, at that time Engineer and Surveyor to the Chiswick Local Board. From 1885 to 1889 he was Assistant Surveyor to the Brentford Local Board, engaged on sewerage works, on filter-presses for the disposal of sewage sludge, and on the construction of a river wall and of new roads.

In 1889 Mr. Strachan was appointed Engineer and Surveyor to the Brentford Local Board. During the five years he held that post, he designed and carried out—in addition to the usual street and sewerage work—an Isolation Hospital, Market, Fire-station and Swimming-bath. In 1894 he left Brentford to become Surveyor to the Heston and Isleworth Board. That post, however, he was unfortunately not destined to hold long—an attack of influenza, followed by pneumonia, proved fatal on the 6th of March, 1895. Mr. Strachan was a capable municipal engineer, of untiring industry, great geniality and scrupulous honesty. He was elected an Associate Member on the 6th of December, 1892.

ELIM HENRY D'AVIGDOR was born at Nice on the 9th of March, 1841, and was educated in France until the age of seventeen. His father was an Italian, the Count d'Avigdor, while his mother was the daughter of Sir Isaac Lyon Goldsmid, Bart. The subject of this notice desired to enter the corps of Royal Engineers, but was disqualified by reason of short sight. He was therefore trained from 1859 to 1862 under Sir John Hawkshaw.[1] During that period he graduated with honours at the London University. His first post was that of Sub-Manager of the Iron and Shipbuilding works of Messrs. Martin Samuelson & Co. at Hull. He was then for three years in British Burma, where he carried out some work for the Indian Government. Mr. d'Avigdor then

[1] Minutes of Proceedings Inst. C.E., vol. cvi. p. 321.

took part in the Western China Survey Expedition of 1867, after which he was for two years Agent for Messrs. Waring Brothers on the construction of the East Hungarian Railway. He then acted for five years as Chief Agent on the construction of the Vienna Waterworks. During that time he read before the Austrian Institution of Engineers and Architects a series of Papers on "Water Works, Ancient and Modern,"[1] and he also published a work on the sanitation of Vienna.[2]

Mr. d'Avigdor settled in England in 1877 and at one time was editor and proprietor of the *Examiner*. He was the author of several sporting books and to the day of his death undertook literary work of all kinds, fiction, essays and reports. He became partner in a firm of contractors for public works and constructed a light railway from Schull to Skibbereen in County Cork; also a portion of the New Zealand Midland Railway, of which Company he afterwards became a director. He was always a keen sportsman and in 1895 became master of the Surrey Farmers' Staghounds. Mr. d'Avigdor did much to help the cause of the Jews, directing his energies chiefly to the furtherance of their schools and to the education of the young. His tastes were literary, artistic and sporting; but he was, above all, a practical man, and he took a delight in overcoming difficulties, such as an engineer always has to face. Mr. d'Avigdor died on the 9th of February, 1895, after seventeen days' illness from intestinal obstruction. He was elected an Associate on the 2nd of May, 1876.

WILLIAM ROSSER, son of Mr. Samuel Rosser, was born at Bryn Mill, Sketty, near Swansea, on the 17th of March, 1829, and was educated at a private school in Swansea. After serving articles to the late Mr. James Hall, of Swansea, he was occupied for some time in making surveys on the Neath and Glyncorrwg Railway. He then opened and worked the Rhydydefed Colliery. In 1852 he went to Llanelly as surveyor to Mr. W. Chambers, the then owner of the Stepney Estates, who died in 1855. Mr. Rosser then acted for Miss Gulston Stepney, Mr. Chambers' successor. She was succeeded by Lieut-Colonel John Stepney (afterwards Sir John Stepney, Bart.) in 1857. Mr. Rosser became his agent and continued to control the large and important Stepney Estates until

[1] The Inst. C.E. Library, Tracts. 8vo., vol. 262.

[2] "Das Wohlsein der Menschen in Grossstädten. Mit besonderer Rücksicht auf Wien." Vienna, 1874, 8vo.

Sir John died in 1877. During that period, Mr. Rosser vastly developed the estates, important colliery lettings were opened out and a large extent of land in the town was laid out for building purposes, the rapid growth of Llanelly for many years chiefly comprising erections on the Stepney property.

Mr. Rosser became agent to the Llangennech Estate, near Llanelly, then owned by the late Mr. E. J. Sartoris, some years after his appointment by Sir John Stepney, and was the means of the erection of Tin Works on part of the estate, that being followed by numerous lettings of building land. He held several other agencies and took a keen interest in starting new industries at Llanelly. He formed brickworks at Machynis in 1855, and subsequently erected Arsenic Works, on the site of which, in 1874, the present Bury Tin-plate Works were constructed. He was the chief promoter of these tin works, and became one of the first Directors, acting in that capacity almost to the time of his death. He was also one of the promoters in 1889 of the Old Lodge Tin-plate Company, of which he became a Director, and was one of the original promoters of the Machynis Tin-plate Company (now the Old Castle Tin-plate Company).

Mr. Rosser was mainly instrumental in obtaining the Act for the reconstruction of the Old Carmarthenshire Tramroad (now the Llanelly and Mynydd Maur Railway) in 1875. He acted in the formation of the line as Engineer, in conjunction with Messrs. Kinipple and Morris. At the time of his death he was engaged as Engineer for the Bury Port and Gwendreath Valley Railway Company, in the matter of its extension from Bury Port to Llanelly. He always took great interest in public matters, and became a member of the Llanelly Local Board of Health in 1857, serving the office of chairman in 1866 and again in 1883. He was also a member of the Llanelly Harbour Commission and took a leading part in obtaining the Act for making a dock at Llanelly in 1864. The work was commenced, but was not proceeded with. He was a Director of the Llanelly Gas-light Company, for which he assisted in obtaining a new Act in 1874. He took an active part in the formation of the Llanelly School Board in 1871, of which he was a member for many years. He also acted as Chairman of the Assessment Committee of the local Board of Guardians, and was a Justice of the Peace for Glamorganshire.

In business matters Mr. Rosser was shrewd and far-seeing, while his agreeable and pleasant manner and high integrity, made him extremely popular among the tenantry and others with whom he had to deal. He was presented with his portrait in oil and a

silver urn by the townspeople of Llanelly and the Llangennech Tenants respectively. He had great experience in valuations and reports of properties, mineral, landed, and otherwise, and his judgment in such matters was considered sound and reliable. Mr. Rosser died on the 27th of December, 1894, from paralysis. He was elected an Associate on the 1st of April, 1856, and was for many years a Fellow of the Surveyors' Institute.

MAJOR-GENERAL RICHARD HUGH STOTHERD, C.B., late R.E., born on the 25th of November, 1828, was the son of the late General R. J. Stotherd, Colonel Commandant Royal Engineers. He was educated at University College School, and at the Royal Military Academy, Woolwich. He entered the corps of Royal Engineers in May, 1847, becoming Lieutenant in October, 1847, Captain in May, 1855, Major in November, 1870, Lieutenant-Colonel in August, 1872, and Colonel in August, 1877. In March, 1853, he joined the Ordnance Survey as a Subaltern, and was employed in the South of Scotland and in Edinburgh until 1861. He was employed on the New Brunswick frontier in 1862, during the time of the "Trent" affair. Between 1866 and 1871 he was Instructor in Electricity and Submarine Mining at the School of Military Engineering, Chatham, and was engaged in the development and organization of the equipments for military field telegraphy and signalling, and in working out a system of defence by torpedoes. In 1871 he was sent with the late Colonel C. C. Chesney, R.E., to report upon the operations of the French and German armies, and upon the siege of Paris during the Commune. Between 1873–1876 he was President of the War Office Torpedo Committee.

In 1881 Colonel Stotherd took charge of the survey in Ireland, remaining at the office in Phœnix Park, Dublin, until 1883. During this period Ireland was in a very disturbed state. He was placed on the Commission of the Peace for the City of Dublin, and received much credit for the tact and discretion he more than once showed in that capacity.

In April, 1883, he was appointed Director-General of the Ordnance Survey at Southampton, which post he held until November, 1886, when he was retired under the regulations of the army as to age, with the honorary rank of Major-General. During his directorate the strength of the survey was at a higher point than it has ever been, owing to the department having been called upon to complete the cadastral survey of England by 1890 instead

of 1900. This work had made great progress before General Stotherd gave up the command, and it was ultimately completed by his successor, Sir Charles Wilson, within the estimate of time and cost prepared by his predecessor, General Cooke. In 1884-5, also, great pressure was thrown on the department during the preparation of the maps of the United Kingdom required by the Boundary Commissioners for the redistribution of seats under the Reform Bill of 1885. For his services in connection with these duties, General Stotherd was awarded the Companionship of the Bath in 1885. During the periods of his command at Dublin and at Southampton, General Stotherd was much liked both by officers and men for the geniality of his manner, and the kindliness he always showed towards everyone with whom his duties brought him into contact. He died suddenly at his residence at Camberley, from heart disease, on the 1st of May, 1895. He was elected an Associate on the 5th of December, 1871.

*** The following deaths have also been made known since the 9th of May, 1895:—

Members.

LAWSON, JOHN; *born* 18 June, 1837; *died* 11 June, 1895. (*Bright's disease.*)

MCRITCHIE, JAMES; *born* 26 September, 1847; *died* 26 April, 1895.

MILES, THOMAS WILLIAM; *born* 26 September, 1840; *died* 11 June, 1895.

PARK, JAMES CRAWFORD; *born* 1 July, 1840; *died* 27 May, 1895.

ROSS, OWEN CHARLES DALHOUSIE; *born* 8 January, 1823; *died* 24 June, 1895. (*Paralysis.*)

WAINWRIGHT, WILLIAM; *born* 2 August, 1833; *died* 21 May, 1895. (*Acute pneumonia.*)

WELLINGTON, ARTHUR MELLIN; *born* 20 December, 1847; *died* 16 May, 1895. (*Heart disease.*)

Associate Members.

BRIDGES, JOHN DOUGLAS ORMOND; *born* 12 October, 1866; *died* 16 May, 1895. (*Typhoid.*)

DESPARD, FITZHERBERT RUXTON; *born* 2 January, 1841; *died* 13 March, 1895. (*Typhoid fever.*)

GRAHAME, WILLIAM HENRY; *born* 3 April, 1858; *died* 8 May, 1895. (*Erysipelas.*)

MCCREA, JOHN BENJAMIN; *born* 28 September, 1833; *died* 27 March, 1895.

STUART, JOHN PERCY; *born* 1 July, 1861; *died* 23 May, 1895.

Associate.

CONWAY-GORDON, Colonel LEWIS, C.I.E. (late R.E.); *born* 12 September, 1838; *died* 25 June, 1895. (*Drowned.*)

Information as to the professional career and personal characteristics of the above is solicited in aid of the preparation of Obituary Notices.—SEC. INST. C.E., 3 July, 1895.

Sect. III.

ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

Levelling with closed Water-Levels. By P. Kahle.

(Zeitschrift für Vermessungswesen, 1894. p. 513.)

The Author gives an exhaustive description of the methods, accuracy, and applicability of levelling with closed water-levels, recording the experience he has had in their use since he first advocated this method of levelling in 1892. Three patterns of this instrument are made. The circular form, consisting of a glass tube bent into a circle 10 to 12 centimetres (3·94 to 4·72 inches) in diameter, is well adapted for use as an auxiliary instrument in levelling with the telescope. The rectangular form 21 centimetres (8·26 inches) in length, and 12 centimetres (4·72 inches) in breadth, may be used for more accurate freehand levelling with or without a staff. The third form is 50 centimetres (19·69 inches) long, and 12 centimetres (4·72 inches) broad, and is affixed to a stand. On very steep slopes it may conveniently replace the telescope level. The cost of the first two patterns is 2*s.* 6*d.* each, and that of the third 7*s.* In freehand levelling the instrument is held with outstretched arm, and with a little practice it may be held very steadily. In this method of procedure, the staff is replaced on sloping ground by the height of the eye above the ground, and on level, or on gently sloping ground, by trees, walls or other vertical objects. Distances are determined by pacing. The Author advocates the preparation of a table showing the shortening of the pace on rising ground. This may be calculated by means of the formula $s+\alpha = s_0 (1-\sin \alpha)$ in which $s+\alpha$ is the horizontal reduction of a pace at the inclination $+\alpha$, and s_0 the mean length of a pace on horizontal ground. With this method of freehand levelling, a difference of level of 100 metres (328 feet) or sixty-two readings, can be determined accurately to $\frac{1}{4}$ metre (9·84 inches). The rate at which the levelling can be carried on is 0·6 hour per kilometre when the difference of level is 100 metres. In this case the uncertainty in the determination of the altitude of the terminal point would be $\frac{2}{3}$ metre (26 inches). On the other hand, with the ordinary level and staff, the time occupied under similar conditions would be 2·8 hours. On level ground, with freehand levelling, the line of sight may be 20 metres (65 feet 7 inches) so that for 1 kilometre fifty stations are required, and the time occupied would be 0·7 hour. The uncertainty of the final point in this case

would be 0·7 metre (27½ inches). In ordinary levelling with the telescope there may be ten sights per kilometre, and the time occupied would be 1·2 hour. The uncertainty in this case, however, would be nil. The freehand method presents the advantages that the observer is not dependent upon others, and that the instrument needs no adjustment.

In freehand levelling with a staff, the mean error for a distance of ten paces (20 to 26 feet) is 2 centimetres (0·79 inch). This result was obtained with a staff designed by the Author for mountain work. It was necessarily very light (3 lbs.). It consisted of four rods, 43 inches long, 0·39 inch thick, and 1·97 inch broad, and was graduated in half-decimetres. With a staff graduated in centimetres and provided with a spirit-level, better results could without doubt be obtained. The best result was obtained by the Author in levelling a distance of 1 kilometre near Jena, where the difference in level was 112 metres (367 feet), and the mean number of readings 146. The length of each sight was approximately 7 metres (23 feet). The time occupied was eighty minutes, and the results obtained were as follow:

Point.	Height Above Starting-Point.		
	Upwards.	Downwards.	Difference.
			Centimetres.
1	14·29	14·26	+ 3
2	29·63	29·68	− 5
3	41·04	41·07	− 3
4	55·90	55·94	− 4
5	75·80	75·86	− 6
6	90·86	90·89	− 3
7	112·16	112·20	− 4

The average time occupied for sighting, reading, and recording, was nineteen seconds per reading. For longer sights, and reading in decimetres, the time was eleven to fifteen seconds. The saving of time as compared with ordinary spirit-levelling is very slight on level ground, but on steep slopes the saving is considerable.

The holder used in conjunction with the 50-centimetre level consists of a cylinder 7·87 inches long and 1½ inch in diameter, on which a rectangular clamping arrangement, 4 inches in length, is fixed. For transport to the ground to be levelled this holder is strapped to one of the legs of the tripod. The weight of the tripod being taken as 3 lbs., that of the holder as ½ lb., and that of the level as ½ lb., the total weight to be transported during the levelling is only 4 lbs., an advantage which on irregular ground should certainly not be undervalued. In levelling with the water-level supported on a tripod, the mean error per sight depends largely on the distance. With a distance of 2 metres on slopes of 35° inclination, millimetres may easily be read. At 7 metres, quarter centimetres may be estimated, and at 12 metres

half centimetres. In levelling a distance of 1 kilometre with a difference in level of 100 metres the time occupied is 2·1 hours, seventy-two stations being necessary, and the uncertainty being 6 centimetres. The levelling of a stretch of ground (173 metres in length) with 100 metres difference in level, and 30° inclination, necessitates fifty-eight stations and occupies 1·3 hour, the uncertainty of the determination being 15 millimetres. Thus, on steep slopes and in other cases where the use of the spirit-level is attended by difficulty, the 50-centimetre water-level may be used with a considerable saving of time and labour, and with no diminution in accuracy.

B. H. B.

A new Declinometer for Orientation in Mine Surveys.

By A. Fennel.

(Mittheilungen aus dem Markscheidewesen, 1895, p. 1.)

With the aid of nine illustrations, the Author describes a new form of declinometer for ascertaining the position of the meridian in traversing underground. A description is also given of a variometer for determining variations in the position of that meridian. In the declinometer a long quartz fibre is suspended in a vertical tube, at the lower end of which a horizontal magnet, consisting of a hollow steel cylinder, is hung. In this tube, which acts as the compass needle, a small mirror is placed transversely. The instrument is attached to the theodolite so as to stand directly before the object end of the telescope. To the latter a short tube is attached containing a half-lens, an inclined mirror, and a glass scale. Through an opening in the upper part of the tube a ray of light impinges upon the mirror and is reflected forward through the scale into the body of the declinometer, where it is further reflected by the mirror in the magnet. It then passes back through the half-lens and through the object-glass.

The variometer is essentially similar in construction to the declinometer. Instead of being attached to the theodolite, however, it is provided with a tripod stand, and has a small telescope for observing the motions of the swinging magnet. The latter contains a total reflecting prism in place of the mirror used in the declinometer.

Careful tests made by the Author show that in order to lessen the influence of torsion of the quartz fibre on the position of the magnet, it is necessary to make the magnet light, to magnetise it to saturation, and to hang it by as thin a fibre as possible. As it was found that mirrors of even 4 millimetres (0·16 inch) diameter gave good images of the objective scale, it was possible in the instruments of most recent construction to give the tubular magnets an internal diameter of only 5 millimetres (0·2 inch), so that with a length of 36 millimetres (1·42 inch) the total weight

of the magnet, inclusive of the tubular holder with hook and mirror, did not exceed 3 grammes (46 grains). The magnets were made of tungsten steel, and were magnetised by a high tension current. With regard to the thickness of the quartz fibres that are capable of safely supporting a magnet of this kind accurate figures cannot yet be given. The diameter of the fibre is, however, certainly less than 0·01 millimetre (0·0004 inch).

Employing the magnets and fibres described, the Author finds that a turning of the fibre through 1° causes a deviation of the magnet of less than 1 second.

B. H. B.

Levelling-Staff for use in Mines.

By O. Ziegler.

(Mittheilungen aus dem Markscheidewesen, 1895, p. 71.)

For levelling underground the Author employs a staff made of stout brass graduated in centimetres on each edge, each alternate centimetre being sharply cut out in such a way that a cut on one edge corresponds with an uncut centimetre on the other. The decimetres are shown by inverted Roman numerals between the divisions, their lower edges coinciding with the decimetre line. These, too, are cut out. The half decimetres are marked by circular cuts. The whole is placed in a wooden frame 4 feet 6 inches in length, on the reverse side of which a ground-glass plate may easily be slid up or down. By illuminating this glass the staff is rendered visible. It is thus a substitute for a glass staff, in comparison with which it presents the advantages of being less heavy (weight 3 lbs.) and of not being breakable.

B. H. B.

A Plumbing Method for Shafts.

By R. G. Brown.

(School of Mines Quarterly, New York, 1895, p. 146.)

With the aid of diagrams, the Author describes a method of plumbing specially useful in shafts where the angle of inclination is but a few degrees from the vertical. In such shafts the ordinary plumbing methods are not suitable and the theodolite is not satisfactory, owing to the large vertical angle and the consequent difficulty in obtaining accurate results. The method is also useful for testing the accuracy of theodolite work in inclines of all angles.

The method will be best understood by assuming the case of a

shaft which, after passing down vertically for some distance, bends off towards a cross-cut that runs into it. The meridian is carried down to the bend by two plumb-lines (*a a*) suspended from the top of the shaft free from the timbers. It is advisable to use fine copper wire with plumb-bobs 8 lbs. or 10 lbs. in weight. A wire (*b*) is then stretched down the inclined part of the shaft. It is secured to the timbering, its position being fixed by moving the ends backwards and forwards until the wire is fairly tangent to the two plumb-lines. If now another wire (*c*) be stretched and secured tangent to the one plumb-line (*a*) and the inclined wire (*b*) and prolonged into the cross-cut, the meridian is secured and can be permanently marked by fixing points in the timbering. If desired the meridian may be secured by setting up a theodolite in the cross-cut approximately in line with *a* and *b* and calculating from similar triangles how far it is necessary to move it.

B. H. B.

Survey of the Königsdorf Tunnel. By — Mieck.

(Zeitschrift für Vermessungswesen, 1895, p. 33.)

The Königsdorf tunnel on the Cologne-Herbesthal railway is 1620·20 metres (5313·25 feet) in length. It runs in a straight line and is lined with brick. The difference in level between the upper surface of the rails and the roof of the tunnel is 26·47 metres (86·84 feet) at 15 kilometres, and 39·30 metres at 15·4 kilometres. From here to 16·1 kilometres the roof averages 39·57 metres above the rails, and then sinks at 16·4 kilometres to 31·92 metres. At a height of 6½ feet above the rails the tunnel averages 7·486 metres (24·56 feet) in width. The contemplated removal of the irregularities in the section of the tunnel by relining it necessitated a careful survey. Owing to the fact that forty-one trains pass through the tunnel in twenty-four hours, this presented considerable difficulty. It was impracticable to determine a straight line as a main survey line between the two entrances to the tunnel by means of the theodolite, and it was consequently necessary to carry out the survey by traversing, intermediate points being so selected that the survey could be interrupted if necessary. For marking these points cast-iron stands, 2 feet long provided with a foot-plate and with a rounded top, were walled in in the centre of the axis of the tunnel, as indicated by the rails, at intervals of 200 metres (656 feet). A hole 4 millimetres (0·15 inch) in diameter in the rounded top served for setting up the theodolite and the objects sighted. Seven of these iron stands were fixed in the tunnel, and outside the tunnel the median line was pegged out. The iron stands in the immediate vicinity of the two entrances to the tunnel served as the starting and concluding points of the traverse. Being fixed at the same height as the top of the rails, these stands served as bench-marks and rendered it possible to

sight directly to the stations of the traverse. The measurements of the lengths required to fix the stations were made on the night of the 11th–12th of December. The night was selected for the subsequent surveying operations also, on account of the longer intervals between the trains—the longest interval being one hour twenty-five minutes. The distances between the station points were measured accurately after wire nails on cross laths, fixed midway between them, had been sighted by the theodolite. A string $1\frac{1}{4}$ millimetre (0·05 inch) in diameter, tightly stretched from nail to nail, clearly showed the survey line for measuring and for subsequent use in taking cross sections. The measuring rods placed along this were 4 metres (13·12 feet) in length, and the theodolite used was 17 centimetres ($6\frac{3}{4}$ inches) in diameter, and was graduated in sixths of degrees, so that it could be read to ten seconds. In the first measurement of the distance 1866·07 metres, as shown on the railway records, gave 1866·04 metres, and on repeating the operation the result was 1866·03 metres.

On the night of 15th–16th of December the angular measurements were begun. For this purpose a portable electric lamp was found useful for reading the verniers. Current for seven hours was supplied from an accumulator carried in a light leather satchel hung at the side, whilst a second accumulator carried on the back, weighing 10 lbs., with a thirty-hours' supply, was held in reserve. As objects sighted, iron rods 3 feet in length and 0·39 inch thick were used. These were sharpened at the base and inserted in the hole in the iron stands. Their verticality was ensured by means of small tripods, whilst they were lighted by a railway guard's lamp, shielded with tracing paper, held behind them, in such a manner that the point of the rod could be accurately sighted. The angles were determined by measuring three times in each position of the telescope. The angles in the tunnel were as follow:—

Station.	Angle.		
Kilometres.	°	′	″
15·1	180	0	9
15·3	179	59	49
15·5	180	0	23
15·7	179	59	44
15 9	180	0	11
16·1	180	1	37
16·3	179	59	26

Levelling was begun on the night of 21st–22nd of December, and a check reverse levelling on the very cold night of 23rd–24th of December showed a difference of 6 millimetres (0·23 inch). A third levelling with a more delicate instrument gave results in good accord with the first, and on these the new gradient was based.

Taking cross sections for measuring the areas and quantities of excavation was done by measuring the irregularities of the contour of the section by means of the following method: The new gradient was marked in each cross section by means of the level

and three pegs. On the top of these pegs a horizontal lath 6 inches high and 6 metres (19·68 feet) long, divided in centimetres on both sides from the centre, was placed and held in position by two men after the zero on the scale had been brought to coincide with the stretched string. On this lath a large right-angle of wood was placed, small iron clamps on the arm above the lath being so arranged that the angle could be slid along the lath. For testing the verticality, a circular spirit-level was fixed. A bevelled-edged measuring rod, 5 metres (16·40 feet) in length, slid along the vertical arm, enabled the height of the tunnel to be directly read in millimetres.

With a view to accelerate the survey, hand sketches for eighty-three cross sections were prepared, showing the station lines and the constantly recurring figures for the distance at which the height of the tunnel had to be measured, as well as the figures for the section required, so that sketching in the tunnel was rendered unnecessary and writing was reduced to a minimum. The lighting was found to be effected most conveniently by torches. On an average eight cross sections were measured per night including the time occupied in pegging out the section.

The time occupied by the survey was as follows :—

	Days.	Nights.
1. Measurement of lengths	1	2
2. Angle measurements	1	2
3. Levelling	1	2
4. Cross sections	4	6
Total	7	12

The survey, it should be noted, was carried out without interfering in any way with the railway service, and without any damage to the instruments.

B. H. B.

Regulations for the Royal Testing Station at Berlin.

(Mittheilungen aus den königlichen technischen Versuchsanstalten zu Berlin, 1895, p. 45.)

The Institution undertakes testing of materials at a standard rate of charges. Detailed information is given as to the testing machines and apparatus in use, which include machines for repeated stresses by Wöhler and by Martens. The mechanical testing Institution is divided into four departments :—metal testing, testing of building materials, paper testing, and oil testing.

The number of shape and test specimens are specified, as is also the manner in which they should be prepared.

An extensive table of charges is given ; and for any special series of tests estimates are furnished on application.

A. S.

Experiments on Bricks, Tiles, and Artificial Stones.

By H. BURCHARTZ.

(Mittheilungen aus den k. technischen Versuchsanstalten zu Berlin, 1894, p. 326.)

The results of experiments on artificial stones, at the Berlin Testing Station in 1891, are supplemented by the results of experiments made in the official years 1891–2 to 1893–4. The tests of 359 different materials are given in tabular form, ten specimens (on the average) of each material being tested. The Tables are made up as follows:—

A. Bricks—
  (1) Ordinary bricks and porous bricks.
  (2) Hollow bricks with longitudinal and transverse holes, and porous hollow bricks.
  (3) Hollow bricks with vertical holes.
  (4) Roofing tiles.

B. Paving tiles and wall tiles of different kinds.
C. Various artificial stones.

The different classes of bricks are divided into whole, three-quarter, half, and quarter bricks.

From the experiments made in these last years it will be noticed that generally an increase in strength has taken place as compared with those of an earlier date. Also, the weathering qualities of bricks in general show a considerable improvement; only in a very few cases have the bricks been found to contain a large percentage of soluble salts. In agreement with this, the results of tests of the raw materials of unburnt bricks show in very few cases considerable additions of prejudicial matter.

More frequently than in former years have bricks been tested as to wearing qualities, and on the average more favourable results have been obtained—a proof that more value has been placed on the attainment of a better method of manufacture, exhibited in the density and uniformity of the materials.

The paving tiles and wall tiles tested deviated little from previous tests, showing that this manufacture has reached a high degree of excellence.

Slag stones have been sent in smaller numbers, showing that they are being less used in practice than formerly. On the other hand artificial stones—artificial sandstone, &c.—are numerously represented.

A. S.

The Tolbiac Bridge. By P. Crépy.

(La Revue Technique, March, 1895, p. 97.)

The bridge is situated in the axis of the Rue de Tolbiac which crosses over the railway lines of the Orleans Station, Paris, and is 54 feet 9 inches wide. The railway lines extend over a width of 531 feet, and the road-bridge had therefore to be made 531 feet long, with as few piers as possible; it is 52 feet 6 inches wide between centres of girders. There are three spans: 167 feet 3½ inches, 196 feet 9 inches, and 167 feet 3½ inches, between centres of piers, but the length of the three girders is 127 feet 11 inches, 275 feet 5 inches, and 127 feet 11 inches, so that the ends of the central girder project as cantilevers 39 feet 4 inches long. The girder is designed as a bow-string girder with a Warren triangulation of 39 feet 4 inches panel-length in the bottom boom; but only the five lengths between the piers are horizontal, while the cantilever booms rise 7 feet and meet at this level the polygonal top boom. Here also are supported the ends of the other girders, which have a similar form but a panel-length of only 19 feet 8 inches and 24 feet 8 inches. The distance between the cross-girders of the central girder is half the panel-length, every alternate cross-girder being suspended from the top boom. The depth of the central girder is 32 feet 10 inches, and the horizontal portion of the bottom boom lies about 4 feet under the roadway. Where the head-room permits it, light lattice arches are spanned across between the diagonals of the two girders, but there is no transverse overhead diagonal bracing. The cross-girders rest on pivot bearings 52 feet 6 inches apart, namely, over the centre of the tubular bottom boom. The object of this arrangement is to avoid the torsion in the main girders when the cross-girder deflects under the load. The roadway is made of concrete laid on reversed buckle plates.

M. A. E.

The Measurement of Water. By A. M. Ryon.

(Journal of the Association of Engineering Societies, January, 1895, p. 78.)

In the course of some experiments on the value of the Montana statute miners' inch, the Author made the following experiments on the discharge of water through an orifice 6 inches deep, and of varying lengths. The orifice was made by fixing two planks 2 inches thick, horizontally 6 inches apart, and placing planks 1 inch thick behind them vertically, at each end, so as to give the orifice the desired lengths. The total head (h), including the depth of water above the centre of the orifice (H), and the head due to the velocity of approach (h_a) was 6 inches.

h_a is taken as being $\frac{1 \cdot 4\ V^2}{2g}$, where V is the velocity of approach.

The discharge through the orifice was measured by causing the same water to flow over a weir 2 feet long and measuring the height above the crest. This discharge is known to a high degree of accuracy from well-known experiments.

Length of Orifice.	Discharge (Q).	Coefficient (C) in Formula $Q = C\sqrt{2gh} \cdot A$.
Inches.	Cubic feet per second.	
6	0·8406	0·593
12	1·7209	0·607
18	2·6174	0·615
24	3·5211	0·621
30	4·4404	0·626

A. W. B.

The Well-Water of the neighbourhood of Bremen.

By Dr. H. KURTH.

(Zeitschrift für Hygiene, 1895, p. 1.)

Since the Hamburg cholera epidemic in 1892, which was proved so undoubtedly to have been caused by the water-supply, numerous investigations have been undertaken to ascertain the considerations which must have weight, in forming a judgment upon water, from a sanitary point of view. One of the chief facts which has been established is, that the chemical examination of any sample of water, upon which so much reliance was formerly placed, is inadequate and untrustworthy. It is indeed a matter of far greater importance to ascertain the actual derivation of any description of water, and the possibility of its contamination with excreta. The question of the value or otherwise of bacteriological researches is a subject upon which much difference of opinion exists, though all are agreed that water obtained from strata at a depth of not less than 6·56 feet, absolutely protected from superficial infiltration, should be free from germs, since the number of bacteria present at this depth below the surface is inconsiderable. Notwithstanding this fact it has been found in numerous instances that in the case of certain wells, carefully secured from pollution, bacteria are very abundant, and it is pointed out that it is not improbable that these germs may be introduced into the subsoil in sinking the well, and that finding there the conditions favourable to their development they may multiply in the deeper levels of the soil. The above apparent exceptions to the definitely ascertained freedom of the deeper layers of the soil from bacteria should not be taken to disprove the well-known facts concerning the sterility of the soil beyond a certain depth, and the Author asserts that his observa-

tions respecting the Bremen water, have enabled him to point to the above theory of accidental introduction as being the probable explanation of the prevalence of germs in many samples of spring waters.

Where, in consequence of pumping, large volumes of water are drawn from the well, it becomes possible by observations on the levels of subsoil-water in the neighbourhood, especially if the strata are porous, to prove that a funnel-shaped depression is produced in the vicinity of the well, and that when pumping ceases there is a general inflow of water into the dip thus formed, tending to refill the same; the inrush of water being most rapid at the greatest depths, and giving rise to a general movement of water in the soil. It fortunately became possible, in the case of certain springs which the Author examined, to prove that a radius of 30 feet round a small house-well is sufficient to protect the water of the same from the infiltration of germs, even when heavy pumping is resorted to.

A description is given of the geological formation of the vicinity of Bremen, by reference to maps and sections, and an account follows of the movements of the water in the subsoil, and the levels of the same at different periods. In all forty wells were examined, the relative positions being indicated on the plan. The Author explains the influence of the depth of the well on the state of the water, and its comparative richness in ammonia compounds and nitrates, and he was able to divide the Bremen well-waters into three groups: 1. Those yielded by wells which were supplied from alluvial strata above the clay, which furnish a permanently clear, agreeably tasting water. 2. Those from wells which passed through the clay and furnished a water rich in iron, occasionally with a mawkish taste. 3. Waters from wells which, owing to their position, partook in their supply of both these varieties of water, but in some of which the characteristics of the second group preponderated. After long-continued and careful pumping, the waters of the second and third categories, if taken from tank-wells (*Kesselbrunnen*) lose their unpleasant taste, and part with a considerable amount of their iron salts. The investigations on these various descriptions of water are described in great detail, and they are accompanied by analyses set forth in numerous tables. The latter were both chemical and bacteriological. In the conclusions it is stated that chemical analysis may be relied upon to determine the permanent characteristics of any given sample of water, taking into due account the changes effected by mutability of the levels of the water in the subsoil. When, however, it becomes necessary to ascertain, in the case of water from suspected localities, the presence of the germs of infectious diseases, bacteriological analysis is alone of value. The hitherto accepted limits of what may be termed permissible values for ammonia, together with nitrous and nitric acids, in water derived from alluvial strata, require to be materially enlarged, and it is possible in deep wells, where the subsoil-water is rich in ammonia, for the nitrous acid to

accumulate to the extent of 2 milligrams per litre. In water of this description, certain varieties of bacteria may abound and may even flourish in great numbers; all these species are, however, so far as is known, non-injurious to health.

G. R. R.

The Removal of Iron from Well-Water by Artificial Rain and Gravel Filtration. By G. Oesten, of Berlin.

(Gesundheits-Ingenieur, 1895, p. 49.)

The Author refers to his original experiments with Dr. Proskauer in 1890, which proved that in the case of water rich in iron salts a fall of 6 feet 6 inches through the air as artificial rain, followed by filtration through a bed of gravel 6 inches in thickness, at a speed of 39 inches per hour, sufficed to so far remove the iron compounds that no further deposit occurred after the clarified effluent passed away from the filter-chamber. He points out that a modification of his process, in which the water drops were replaced by a coke-tower and the bed of coarse gravel by an ordinary sand-filter, such as is commonly employed for the purification of water, the speed of filtration being still 39 inches per hour, had found more favour than his former plan, and had given rise to an erroneous opinion that the process first employed had not been a success. In fact, experiments carried out at Kiel, where they had coke-towers and sand-filters working side by side with the artificial rain and gravel-filters, had, owing to inadequate provisions, led to false conclusions respecting his invention, and notably to the rejection of his process at the works at Charlottenburg. This was because it was alleged that the action of the iron deposit, which penetrated some depth into the gravel, would hinder the working of the filter. But the Author states that such is not the case; and he has recently had an opportunity of carrying out two small works upon the system he advocates, which had demonstrated the efficiency of the plan in question.

Illustrations are given of the arrangement adopted in the case of the cardboard works of Messrs. Hochstein and Weinberg, in Berlin, and for the railway station at Kreuz on the Ostbahn. In the former about 2,200 gallons per hour are pumped up to the top of the building. The water passes through three rose-jets in the form of fine rain and drops on to a bed of coarse gravel, having a superficial area of about 107 square feet. This gravel is arranged on a perforated grating, 6 inches from the bottom of a tank, 3 feet 3 inches in depth; the thickness of the gravel is 12 inches. The water on passing through the gravel-filter rises in an outer lining-tank to an overflow-pipe, which is at such a level as to give a maximum head of 15·7 inches of water on the filter. The working of the apparatus is explained by reference to the drawings. Arrangements are made to wash out the filter by a reverse current.

After two weeks' working the crust of iron-deposit on the top of the gravel has to be broken up by means of a toothed roller, and when the gravel is washed out the top layer of 2 inches to 3 inches in depth has to be lightly raked over to allow the iron to be washed away, and after a more lengthened use it may be necessary to employ a spade to turn up the deeper layers of the filter-bed, but at present a wash out once a month has sufficed. Nearly all the dissolved iron is removed by the treatment. The quantity of water dealt with at Kreuz is smaller than in Berlin, viz., 1,100 gallons per hour, but the arrangements, of which an illustration is given, are very similar. The Author states that his process has by these means been found to answer every purpose, and that he understands that at Charlottenburg the coke-towers have recently been replaced by walls of masonry. It will perhaps shortly occur to the authorities that the walls may be omitted and that the same results will follow if the water has a free drop in the open air.

G. R. R.

The Drainage of Paris.[1]

By — BECHMANN and — LAUNAY.

(Annales des Ponts et Chaussées, March 1895, p. 257.)

This article is in three chapters, describing respectively the present system of sewerage of the city of Paris, the methods of disposal of the sewage, and the extensive works in progress, or about to be commenced.

The drainage of Paris is all collected in three main sewers, of which two are on the right bank of the river and one on the left bank. One of the two on the right bank intercepts the drainage of the high ground to the north of the city, having an area of about 3,200 acres, and it has its outfall at St. Denis. The main sewer of the left bank drains an area of about 7,680 acres. It passes under the Seine and joins the second sewer of the right bank just above its outfall at Clichy. The latter drains an area of about 6,500 acres. The dimensions of these sewers are given. The sewers are everywhere made so as to accommodate water-pipes, telegraph and telephone wires, pneumatic-despatch tubes, compressed-air mains, &c. They are everywhere well ventilated and accessible, the inside depth on the axis being never less than 5·9 feet. The lengths and sections of the various types of construction existing are given. The main sewers are flushed by means of movable flood-gates, carried in some cases by boats floating in the stream of the sewer, and in other cases, where the construction of the sewer forbids the use of boats, carried by wagons running on rails. The flood-gate is lowered nearly to touch the bottom of the sewer. The water is banked up behind it,

[1] Minutes of Proceedings Inst. C.E., vols. xxiv. p. 257; liii. p. 193.

and a vigorous sluicing effect is produced. The sand so removed is deposited again further on and progressively moved towards the outfall as the boat or wagon carrying the flood-gate advances under the pressure of the water retained. A similar effect is obtained in the siphon under the Seine by sending through it from time to time a wooden ball, 6 inches less in diameter than the siphon. The ball remains in contact with the upper surface by flotation. Its motion is impeded by friction, and it therefore creates an obstruction, and the water is headed up behind it and gives a sluicing current under it sufficient to carry along any deposit.

These methods could not be used in the smaller sewers, and flood-gates worked by hand are employed in them for flushing purposes. Of late years all new sewers have been provided with flushing reservoirs fed by the fresh-water mains, which is more satisfactory, in the case of the secondary sewers, than depending on the sewer water alone for flushing purposes. The flow at the Clichy outfall in 1893 amounted to nearly 14 million cubic feet per day on the average.

The pollution of the river below Clichy made it imperative, thirty years ago, to find some means of disposal of the sewage other than pouring it in a crude state into the Seine, and after experiments had been made, it was decided in 1869 to adopt the method of purification by filtration through the soil and by vegetation. The land utilized for the purpose is almost surrounded by a loop of the river between Clichy and Argenteuil. The area irrigated has been constantly added to since the system was adopted, until it now amounts to 1,918 acres. The amount of sewage water used for irrigation amounted to 1,180 millions of cubic feet in the year 1893. The health and prosperity of the district are unquestionable. The rental of the irrigated land has risen from £1 5*s*. to £7 5*s*. per acre, while the population has more than doubled since 1872. The sewage farm is supplied by branch culverts from the three main sewers mentioned above. One of these is at a sufficient elevation to reach the site by gravitation; the other two deliver into a pumping-station with pumping-engines of 1,100 HP. The irrigated lands are on the left bank of the Seine, and the mains are carried across the river along road-bridges, to join the distribution channels. Details of the construction of these channels are given and also an analysis of the sewage. The land is used for market-gardening and the production per hectare of various crops under irrigation is given. The gross value of the crops obtained is from £50 to £160 per acre. The effluent water from the subsoil of the district is quite innocuous, a fact which is established by numerous analyses as well as by ordinary observation. The cost of establishing this irrigation system has been, up to the present, £208,000, and the expenses of maintenance are £16,700 per annum. It is estimated that the increased income from irrigated lands obtained by owners and occupiers amounts to £25,600 per annum.

The law passed by the French legislature in 1894, established, after prolonged discussion, the principle known in France as "*tout à l'égout*," in its application to Paris. This means that all other methods of disposal of sewage were to be abandoned and the connection of all houses with the sewers became obligatory. A sketch is given of previous legislation on the subject, and the principal provisions of the law just mentioned are summarised. It authorises the city of Paris to raise a loan of £4,580,000 to be expended on completing the drainage system of the city and in extending the irrigation works so as to treat the whole of the sewage at the outfall. It will be necessary for this purpose to acquire and prepare for irrigation 8,900 acres of land, and much more than this area of suitable land for the purpose is available. The works of both classes about to be undertaken under this scheme are described. In appendices to the Paper, the laws of the 4th of April, 1889, and the 10th of July, 1894, relative to the drainage of Paris, and the decree of the 8th of August, 1894, issued under the authority of the latter law, are given in full.

C. F. F.

The Pollution and Cleansing of Rivers, in accordance with Experiments on the Water of the Oker.

By Dr. R. Blasius and Dr. H. Beckerts.

(Deutsche Vierteljahrsschrift für öffentliche Gesundheitspflege, 1895, p. 337.)

It has always been one of the strictest requirements of hygiene that public watercourses should be kept free from contact with domestic and industrial waste waters, and this is all the more important in the case of towns which derive their water-supply from rivers passing through them. The city of Brunswick makes use of the water of the Oker for its supplies for drinking and other purposes, in accordance with the scheme adopted by the municipal authorities about the year 1862, at which time a chemical investigation was undertaken of the water above the town, which was declared to be suitable for this purpose, after treatment by subsidence and sand-filtration. At that date there were but few industrial establishments which drained into the Oker located above the town, and Wolfenbüttel, situated about 10 miles above Brunswick, was almost entirely a midden town, and therefore scarcely any of its sewage entered the river.

The Brunswick waterworks, comprising settling-pond and filter-basin, were opened in 1865, and they have since that date been from time to time extended in accordance with the growing needs of the town. In the period which has since elapsed, the conditions with respect to the districts above the town have been considerably changed; a series of beet-sugar manufactories have been

erected which discharge their waste liquors more or less impure into the Oker, and in the town of Wolfenbüttel many houses provided with water-closets now convey their drainage direct into the river. Notwithstanding all this, the waterworks have hitherto been able to furnish a suitable supply of filtered river-water. Shortly after 1880 complaints were received during the winter months of the quality of the water, and from the year 1887 onwards the Authors have carried out a series of weekly analyses, both chemical and bacteriological, of the service-water. During the severe winter of 1887–88, and again in the following winter, the number of germs per cubic centimetre present in the service-water rose rapidly from below 30 to 8505, the water had a nasty taste, and occasioned violent complaints. In subsequent years, during and after the active period of the sugar factories (the months of November and December) the same state of things occurred, and legal steps were taken to compel the offenders to abate the nuisance. In consequence of this action the Authors were commissioned to report upon the pollution of the River Oker throughout its entire flow, and these observations have been conducted continuously since August 1890. A description is given of the whole course of the river, which rises in the Hartz Mountains, and flows into the Aller, a tributary of the Weser. The volume of water passing Brunswick varied somewhat widely from a monthly maximum of 85½ millions of cubic metres in April 1891, to 2½ millions of cubic metres in July 1893. Its quality is likewise very variable, as is also its contents in bacteria. The results of the different analyses are set forth in tables, and also the composition of the effluent from the beet-sugar works, which constitutes the most important source of pollution. There are likewise numerous tables to indicate the self-cleansing effect of the flow of the river under various conditions above and below Brunswick. As it was proved that the waste from the sugar factories was the chief cause of the foul state of the Oker, it was made compulsory, after 1891, upon all owners of works situated in the territory of the state of Brunswick to clarify these foul liquors by irrigation, and the marked improvement effected by these means is shown by analyses of the river-water before and after this remedial process was generally adopted. In a tabulated form a comparison is also made between the river-water and the filtered service-water at stated intervals throughout the years 1890, 91, 92, 93, and 94. The conclusions formed by the Authors are summarised as follows:—

(1) The pollution of rivers is chiefly caused by domestic fouled water, and the waste from factories.

(2) The self-purifying powers of rivers depend upon (*a*) the extent of the dilution to which the polluting matters are subjected; (*b*) the access of atmospheric air, (*c*) the temperature, and (*d*) the exposure to sun- and daylight.

(3) The domestic waste water, and that from industrial establishments, in so far as they contain organic substances liable to putrefy

(specially in the case of sugar manufactories), can best be purified by irrigation.

(4) Gravel- and sand-filters are best adapted to purify upon a large scale, river-water polluted by excreta and manufacturing waste liquors, and to convert the same into wholesome drinking- and service-water.

G. R. R.

Further Investigations respecting the Disinfecting Power of Soap-Solutions. By Dr. MAX JOLLES.

(Zeitschrift für Hygiene, 1895, p. 130.)

Reference is made to the earlier investigations of the Author[1] in which the destructive effect of soap-solutions upon the cholera bacillus was demonstrated, and the same enquiries are here extended to the germs of typhoid fever and the bacillus coli communis, these being two of the most usual species which have to be dealt with in the treatment of soiled linen. In this case only one variety of soap was employed, in the place of the five kinds used in the previous tests, as it had been proved that these soaps all of them differed but little in their action upon the germs. The soap made use of in these experiments yielded the following results upon analysis:—

	Per Cent.
Fatty acids	67·44
Total alkaloids	10·40
Free alkali	0·041

Ten sets of test-solutions were made up in sterilised distilled water, containing from 1 per cent. to 10 per cent. of the above soap, and in each case 100 cubic centimetres of the solution were introduced into sterilised Erlenmeyer flasks. Each flask also received 20 cubic centimetres of freshly prepared meat-juice-peptone bouillon, duly impregnated with germs of typhoid fever and bacillus coli communis. After three days' cultivation at various temperatures, test-plates were cast in the usual way and examined microscopically. The results obtained are set forth in Tables. Four sets of ten tests each were undertaken with the typhoid fever cultures and three sets each of ten different strengths with the bacillus coli communis.

As the outcome of the experiments the Author observes that, in the case of the typhoid bacilli, the disinfecting properties of the soap-solution are much more marked at low temperatures (4° C. to 8° C.) than at ordinary temperatures. There is, practically, little difference in the disinfecting powers of the dissolved soap at any range of temperatures between 18° C. and 30° C. When rags infected with the germs were treated in the soap-solution the action of the soap was very marked, and even a 1 per cent. solution was

[1] Minutes of Proceedings Inst. C.E., vol. cxvi. p. 434.

injurious to the germs in fifteen minutes, and a 6 per cent. solution resulted in the entire destruction of all germs with an exposure of equal duration.

A 3 per cent. solution was fatal in one hour, and in a 1 per cent. solution no germs remained capable of development after two hours' immersion. The tests of the soap-solution with the bacillus coli communis were not quite so favourable to its disinfecting action as in the former case, but this would be readily understood because of the far greater powers of resistance which these bacilli are known to possess. At low temperatures a 2 per cent. solution was fatal in six hours. As the temperature rises the action of the solution diminishes, but even in the case of these bacilli an 8 per cent. solution destroyed all germs in thirty minutes, a 6 per cent. solution in one hour, and a 3 per cent. solution in six hours. The Author concludes that, in consequence of its antiseptic action, soap furnishes a powerful and safe disinfecting agent for certain of the most prevalent disease germs.

G. R. R.

The Dorpat Cholera Epidemic in the Autumn of 1893.

By Prof. Dr. B. Körber.

(Zeitschrift für Hygiene, 1895, p. 161.)

Though the number of officially-reported cases only amounted to ninety-nine in a population of about 40,000, the Author considers that his observations upon this cholera outbreak may be useful because he treated nearly every patient himself, saw their dwellings, and collected from the house inmates and neighbours every possible particular respecting the attack. He was, moreover, charged with the duty of carrying out the requisite disinfection; he arranged for the supply of victuals for the sufferers, and was daily engaged in the cholera district from September 1893, to February 1894. By reference to a plan of the town he explains the nature of the locality where the outbreak occurred, and indicates the infected houses and those whose occupants escaped the disease. The River Embach, in passing through the town, makes a sharp bend to the right in the down-stream direction, and the quarter attacked lies at the summit or exterior of this bend. The nature of the site, which is drained only by ditches and is liable to annual inundations, is described. The road-levels have from time to time been raised by the deposition of all kinds of rubbish, so as to be available while the waters are out, at the time when the river is in flood; the yards and gardens which still remain at the original level become ponds or lakes during inundations. The houses—which are generally of one story, and have high sub-structures to raise them above the flood-line—are inhabited by the lowest class of labourers and are terribly overcrowded. The well-water is for the most part bad and the

drainage receives no attention. A chemical analysis of a sample of the water is given. The bacteriological tests indicated the presence of as many as 900,000 germs per cubic centimetre. The privies, which are as a rule situated away from the houses, are wholly neglected; they are all connected with cesspits, which latter are usually of small size, though in one case no less than 1,740 cubic feet of excreta were found to be stored up. In order to avoid too frequent emptying and the inquisition of the sanitary officials, secret storage cesspits were in some instances provided, into which the contents of the regular midden could from time to time be removed. The annual inundations provided a ready way of getting rid of these accumulations of excreta and of distributing the same free of cost over the surrounding gardens. The residents in this district belong to the poorest classes, and live in a state of chronic hunger and dirt.

The Author excludes four of the officially-reported cases, reducing the number of patients to ninety-five, of whom sixty-eight (equivalent to 72 per cent.) died, and this exceptionally high percentage of mortality led him to the belief that many of the less serious cases escaped notice. The dread of the cholera hospital caused much concealment of illness, and in one instance, as soon as the ailment of a married couple had been pronounced to be cholera, they fled. The woman returned twenty-four hours later; the man was found two days afterwards dead in his wagon at the outskirts of the town, at the point where the horse had stopped. Various reasons are given for the ill-repute of the hospital, one of them being the high death-rate therein as compared with the frequent recovery of patients who eluded the officials. From careful inquiries made subsequently, the Author considers that in the district of the outbreak, with 1,360 inhabitants, there were 128 cases and sixty deaths, or ninety-four cases per 1,000, with a death-rate of forty-four per 1,000. These figures prove the epidemic to have been a very severe one, for, according to Hüppe, only in two districts in Hamburg did the mortality exceed twenty-nine per 1,000. The causes of the disease are discussed, some of them being attributed to the use of the water of the River Embach, which was very much polluted, and some of them to infected well-water, which was highly charged with excrementitious matter.

The cholera cases in each house and in each street are dealt with seriatim, and a Table is given showing the results of the bacteriological analysis of twenty-eight polluted wells, nearly all of them extremely shallow. Some of the cases investigated show the danger of infected water to other more healthy districts; thus, vegetables in the market, washed in suspected well-water, caused a man and his wife to sicken with cholera who partook of them uncooked in quite another locality.

The most important precaution to be observed in an outbreak of this kind is the effectual disinfection of the dejections, and for this purpose quick lime, which was freely dispensed to the inhabitants, was found to answer extremely well. It was used with water as

milk of lime as a disinfectant, and employed, crushed into small lumps, in cesspits and privies, 220 lbs. being thrown, in the first instance, into every cesspit, after which the contents were well stirred. If after twenty-four hours the midden contents failed to show an alkaline reaction, more lime was added. All ditches and watercourses were disinfected in a similar way, and all the worst wells were conpulsorily closed.

The Author discusses the probability of a fresh outbreak of cholera and predicts that although the germs have for the present been destroyed, if the disease is again introduced it must spread in consequence of the extremely defective sanitary condition of the town and the faulty character of the drinking water.

G. R. R.

The Vibrios found in the Waters of Giessen in the Autumn of 1894. By Dr. KUTSCHER.

(Zeitschrift für Hygiene, 1895, p. 461.)

During the course of 1893 the various streams in the vicinity of Giessen were repeatedly examined bacteriologically in order to obtain a solution of the question whether it is necessary that the appearance of vibrios, similar to those of cholera, must be preceded by an infection of such waters with cholera matter, or whether the presence of such organisms is wholly unconnected with that disease. It was not then possible however to isolate any vibrios of a suspicious character. In the middle of July 1894, the Author resumed his investigations and continued them until the 5th of August, again without success, though, owing to the relatively small number of analyses, a definite result was scarcely to be expected. Then, suddenly, on the 28th of August, there arose at Bürgel, a village in the district watered by the Lahn, a small epidemic of cholera, and infected excreta were discharged into the village brook, which is indirectly a tributary of the Lahn. In order to trace the possibility of an infection of the Lahn at Giessen with cholera germs the Author again took up his experiments on the 2nd of September, and in the period between that date and the 5th of November he carried out 206 tests of the water. The samples were collected at various points on the river and its tributaries with due precautions, and they were examined bacteriologically by cultivations on gelatine plates and in various media; the details of the methods adopted are given. Towards the middle of September the cultures began to contain colonies of curved organisms which more or less resembled morphologically the cholera vibrios. The different cultures are classed by the Author under separate heads, and he refers those of the first three groups to a family whose prototype is the Vibrio Finkler-Prior. On the 17th of September he isolated, from a sample of water obtained below the town, the Vibrio Metschnikoff, but no further colonies of these vibrios could be cultivated. Then on the

27th of September appeared some vibrios which manifested the greatest possible resemblance to those of cholera, and these were cultivated in rapid succession until the 15th of October. They agreed in very numerous particulars with the typical vibrios associated with cholera, and throughout their various modifications they did not pass beyond the border lines which distinguish these organisms. The Author discusses the possibility of the connection of these suspected vibrios with the cholera-outbreak at Bürgel, and he shows that if they passed with the current down-stream they might have traversed the total distance of 24·8 miles and reached the spot where the sample was procured in about five days. They should, if they came with the current, have thus showed themselves on the 10th of September, whereas they were not found until the 27th of September. He therefore, for this and other reasons, abandoned this theory and sought other explanations for their presence. He investigated the sewage matter of Giessen, and isolated certain vibrios of a character closely resembling those found in the river, and he also analysed the farmyard dung produced as manure in farms in the vicinity, and he successfully isolated, by pure cultures of pigs' dung, two descriptions of vibrios which answered in very numerous particulars to certain of those described. Horse and cow manure when analysed bacteriologically produced negative results. The analyses are recorded in detail in five sets of tables, which give all particulars respecting the vibrios cultivated in different media, on gelatine, blood-serum, potatoes, bouillon, and peptone-solution, together with observations upon their pathogenic character as tested by their behaviour when injected into guinea-pigs, mice, and pigeons.

G. R. R.

The Hygienic Utility of Light. By Dr. W. Kruse.

(Zeitschrift für Hygiene, 1895, p. 313.)

It is not necessary to dwell upon the importance of light for the life of mankind; but from the health point of view it becomes a matter of interest to ascertain the need of the same quantitatively. In certain cases, as for instance in that of the organs of vision, rules have been laid down which to some extent claim an approach to mathematical accuracy, but in general no clear conception has been arrived at respecting the significance of light with regard to health. The Author discusses the known facts, in order to ascertain the data upon which such knowledge is based. The influence of light, as it is perceived by the organs of vision, needs no discussion; but while it is undeniable that light stimulates and excites the senses and mental action, it is well known that owing to the ready adaptability of man to his environment, he can undergo deprivation from light for long periods without apparent inconvenience. The absence of light may indeed have an effect upon the temperament, as evidenced by the quiet earnest disposition

of the miner, while the long duration and abundance of light may cause the undoubtedly lively character of Southern races, or those approaching the Equator. Free access of light has ever been deemed necessary for a healthy dwelling, and physiological investigations have shown that light is needed from the hygienic point of view. Three groups of experiments have been adduced in support of this theory:—First: many authors have alluded to the chemical action, chiefly measured by the amount of carbonic acid gas evolved by the higher animals and by human beings, which is intensified under the influence of light. This has been thought to depend upon reflex action, not only through the eyes, but also through the skin. The proofs in this case, however, rest upon a very slender basis. Second: light has been deemed to have an accelerating action upon the development of embryos and new-born animals, but here the results of experiments have been very contradictory. Third: certain investigations with respect to the action of light upon the skin have tended to show that the organism of the higher animals is opposed to a too powerful degree of light, as evidenced by certain changes of colour, which would seem to indicate a species of protective influence. Physiological experiments do not therefore prove the beneficial action of light, or conversely the deleterious action of the want of light. As a case in point, colliery ponies, which are often kept underground for years in absolute darkness, show no ill effects. Lastly, certain observations are quoted relating to the effect of light upon sick persons, as in the case of the so-called "sun baths" for dropsy and gout, but on the other hand the exclusion of every ray of light from persons suffering from small-pox has been held to be extremely beneficial.

Passing on to certain indirect effects of the operation of light, allusion is made to its well-known influence in chemical action upon organic and inorganic substances devoid of life; on its biological importance for plants containing chlorophyll, and its undoubted action upon the lowest organisms, devoid of chlorophyll, which latter has only been recently made known by experiments on the dry-rot fungus. In connection with this branch of the subject the Author calls attention to the fundamental fact that light exerts a deleterious action upon living bacteria, as shown by experiments with anthrax germs in distilled water, exposed to sunlight, in which these bacteria were wholly destroyed in two hours in bright sunshine. The rapidity of this action of light depends upon the amount of oxygen evolved. With a gradually increased intensity of illumination, the disinfecting action of the light is augmented, but very feeble illumination fails to stimulate, and acts rather as a hindrance to the development of the germs. It is shown that those rays of the spectrum which are most sharply refracted are chiefly answerable for the antiseptic working of light. Light does not exert its disinfecting action in consequence of its warmth, but the effect of illumination is intensified as the temperature rises. The greater the number of bacteria present in a given volume of the medium exposed to the action of light, the less

rapid is its effect. Further, the medium in which the illumination exerts its influence is very important as regards the results to be obtained. Owing to the operation of light, fluid media which contain complicated nitrogenous compounds are so far changed as to cause them to assume antiseptic properties in respect of bacteria. These changes are due to the influence of the oxygen in the atmosphere, and take place more or less rapidly in accordance with the intensity and duration of the illumination. It is, however, impossible to attribute this action upon bacteria solely to the changes in the medium. As the general outcome of his investigations, the Author asserts that light is at once the cheapest and most universal of disinfecting agents—even diffused daylight has its good effects in checking the development of bacteria.

G. R. R.

Notes on some New Methods employed in Central Asia for carrying out Hydraulic Works.

By — Poklewski-Koziell.

(Mémoires et compte rendu de la Société des Ingénieurs Civils de France, April, 1895, p. 600.)

The Author commences with two instances of what he considers novel work. In the first, a bend of the River Cache threatened to undermine the bank of the Acoustan Canal, and thus deprive the town of Kuldja of water. Across a shallow portion of the Cache above the point where the canal was threatened, the Author planted a series of tripods of poplar trunks, 6 to 8 inches thick and 10 to 13 feet long. The legs of the tripods overlapped and formed an open lattice-work. Against the tripods were placed long fascines, cutting off the threatening bend of the river; against the fascines were piled stones, and the interstices of these filled with grass and straw, till little by little a dam was formed, the river rose, and flowed into a new channel cut for it across the bend. The dam was over 328 yards long, and took six hours to construct; the collection of materials and cutting the new channel occupied three days, and about 6,000 men and several hundred two-wheeled carts were employed.

The second instance dealt with the mountain streams feeding the River Ili, and which, flowing across the Acoustan Canal, did great damage when swollen by heavy rains. To mitigate this, trenches were cut parallel to the canal to cause the deposit of the stones and sand carried down by the streams, and opposite these trenches the section of the canal was flattened and the lower bank edged with fascines. The aim was to spread out the flood-water so that its depth over the trenches and canal bank should not exceed 12 or 15 inches. In this way the damage to the canal from heavy rains was confined to minor displacements of the pitching and fascine-work.

A few notes on filtration, especially round openings in dams, follow. The Author is in favour of wide shallow foundations in place of deep ones, where the ground is soft; and he describes the foundations for a water-mill, three storeys high, on loose sand traversed by springs. He used no cement or hydraulic lime, the work being as it were floated on a cushion of fascines, all settlements being made good till movement ceased.

The Author then gives a description of some work executed at Sultan-Bent on the Murghab for the irrigation of Merv. Here he found ruins of an old brick dam and sluices on a very large scale. Remains of fascines were found in this old work, while the ground on which the new work was built was a fine, water-bearing sand, covered with a bed of silt. The Author describes his methods of making bricks and hydraulic lime for the work, several millions of the former, and about 2,000 tons of the latter being used, in addition to bricks from the ruins. He also describes his use of a mortar formed of lime and clay, as suggested by Vicat, and states that he found no traces of sand in the mortar used in the ruined work. He mixed clay with a fat, quick lime, and on adding water sufficient heat was evolved to produce a mortar, which he describes as equal to that made with the best hydraulic lime.

The Author decided to rebuild the old dam at Sultan-Bent and make a sluice and overflow canal on the right of the river, similar works on the left bank to be made later. The river bed was first widened to 180 feet to facilitate the passage of floods during construction. The dam was founded on mats formed of crossed faggots, the mats being each 32¾ feet square, and 4 feet 10 inches thick. The upper side was divided into pockets, 2¼ feet square and 2 feet 5 inches deep, by interlaced twigs, to receive the bricks by which the mat was sunk into position. Each mat weighed 33,000 lbs., the bricks adding about 40,000 lbs. These mats formed a floor, about 197 feet long and 66 feet wide, and on this were placed heavy fascines, parallel to the stream, 16 feet 5 inches long and 3¼ feet in diameter, weighing some 5,300 lbs. each. These were swung into position from a mooring up-stream and then sunk. They were placed across the stream in a double line, this width being increased as soon as the line across was formed. More fascines followed, the first rows sinking into the sand and disappearing; but gradually the settlement ceased, and as the work rose above the bottom of the river, bundles of hay, weighed down by bricks, were packed against the fascines, and the river higher up was disturbed so as to promote a deposit in order to staunch the fascines. In this way the Author raised the level of the water 32 feet 10 inches, and formed a reservoir over 26 miles long. Progress was slow to allow the work to settle thoroughly as it proceeded, and to form the deposit on the up-stream side. The Author at the same time constructed two overflows and a sluice in concrete faced with brick, as well as a sluice in fascines and concrete.

R. B. M.

The Dimensions of Gas-works Apparatus.

By M. REISSNER, Berlin.

(Journal für Gasbeleuchtung, 1895, p. 17.)

Various rules are in use for determining the dimensions of the apparatus on a gas-works; these are sometimes based upon the experience at a particular works and may then only be applicable to special conditions; but the averages of the experience from a number of works are of more general use. Mr. Reissner, the Manager of the Berlin Municipal Gas-works, has drawn up the following rules which, after many years' experience, have been adopted in the various works under his charge.

For estimating the necessary dimensions of the various apparatus the maximum gas-production of a December day is taken, and from this the so-called normal dimensions are calculated.

Retorts.—With Silesian coal, 15 per cent. of retorts in reserve, but if in any one of the four or five works some benches are unavailable for one whole winter, in consequence of rebuilding, &c., then a reserve of 10 per cent. may, as an exception, be regarded as sufficent.

Condensers.—A minimum of 3·65 square feet of cooling surface per 1,000 cubic feet of gas per twenty-four hours or, for completely furnished works, 4·56 square feet of cooling surface per 1,000 cubic feet of gas. The Berlin form of condenser is a cylinder 4·26 feet diameter and 28·86 feet high, with eleven internal cooling tubes 4 inches in diameter; the outer surface, together with the connecting pipe to the adjoining cylinder, having nearly the same air-cooling surface as the water-cooling surface of the inner pipes.

Scrubbers, filled with boards. A minimum of 5 cubic feet capacity per 1,000 cubic feet of gas per twenty-four hours, and for completely furnished works, 6 cubic feet.

Exhausters.—One exhauster in reserve at each works.

Purifiers.—Five trays with oxide of iron in each, 1·17 square feet of area per 1,000 cubic feet of gas per twenty-four hours; where there are four purifiers, all are included in the calculation. In cases of necessity, for one winter, and with tolerably fresh purifying material, 1 square foot area per 1,000 cubic feet of gas will suffice.

Catch-Purifier.—With four to six trays of sawdust, one catch purifier to each four oxide purifiers and of the same dimensions.

Station-Meters.—A maximum of eighty revolutions of the drum per hour. On account of unavoidable irregularities in the production, the maximum quantity of gas passing per hour should be estimated at 10 per cent. above the average hourly production.

Gasholders.—A minimum of 80 per cent. of the greatest daily production. In Berlin it is at times difficult, with this minimum, to keep all the retorts regularly charged, especially on Mondays.

Works Connections.—Outlet main from five beds of nine retorts

in each, 12·5 inches diameter. From the point where the mains from the retorts unite into large mains, the latter in Berlin are 37·4 inches, 39 inches, and 39·37 inches diameter, giving an estimated velocity of 9·84 feet to the gas. With smaller mains the velocity should be between 6·56 and 9·84 feet.

Cross Connections between two mains on the same works may have a velocity for the gas not exceeding twelve feet. For the outlet main from the works to the town it is estimated that in Berlin there is a loss of pressure in the large mains of one inch in 2,734 to 3,280 yards length of main, with the greatest hourly output on a maximum December day, and this maximum output is about one-eighth of that of twenty-four hours.

C. G.

Comparative Tests of various Incandescent Gas-Burners.

Professor W. Wedding, Berlin.

(Journal für Gasbeleuchtung, 1895, p. 49.)

The greatly extended use of the Auer, Welsbach, incandescent burner in the last few years has given rise to competition in the manufacture of the incandescent material, and in the endeavour to make it stronger and more durable. The Author made experiments for the purpose of comparing photometrically various incandescent burners. For this purpose he obtained two Auer burners and two each Trendel and Benas burners. These burners were fixed side by side with governors, and were all lighted at the same time, and the illuminating power of each was determined, after they had burned some time with an average pressure of $1\frac{3}{10}$ inch; they were also again tested after burning for 232 hours, as were also burners from Stobwasser & Co., and C. Kramme. For the photometrical tests, a single burner was fixed on the photometer bar and carefully regulated; the incandescent bodies were then, each in turn, fixed on this burner and tested at the same pressure, the consumption being noted. For the comparative source of light, an incandescent electric lamp, compared with a Hefner standard, was used, and this was verified before each series of tests, the tension of the electric lamp being regulated by a Weston's voltameter. The illuminating power was only determined in a horizontal direction, the average of six to ten observations being taken.

The gas-consumption was not corrected for barometrical and thermometrical variations, but was taken as registered by the meter, and, as considerable barometrical variations occurred during the tests, the differences may be partly due to this; but the principal cause of such differences was the irregular shapes of the mantles, as according to the variation of the angles of their sides from the vertical, more or less light is given in a horizontal direction.

The measured values of the illuminating powers for both series of six burners are given in a table, of which the following is an abstract:—

	Consumption per Hour.	Illuminating Power.
	Cubic Feet.	Candles.
Auer burner, when first light lighted	3·81	57.3
„ „ after 232 hours	3·88	38·4
Trendel burner, when first lighted	3·67	20·1
„ „ after 232 hours	3·85	13·2
Benas burner, when first lighted	3·74	23·6
„ „ after 232 hours	3·88	6·4
Stobwasser burner, when first lighted	3·60	31·6
„ „ after 232 hours	3·92	4·0
Kramme burner, when first lighted	3·60	22·7
„ „ after 232 hours	3·88	9·8

From the results of the experiments it is concluded that the Trendel, Benas, Stobwasser and Kramme mantles are not nearly so good as the Auer mantles. They do not, even when new, fulfil the conditions upon which they were placed upon the market. The Trendel mantle, with a consumption of 3·63 cubic feet per hour was said to give an illuminating power equal to about 44 candles, but less than the half of this was obtained in the experiments. For the Benas mantle an illuminating power of 60 candles was claimed with 3·63 cubic feet hourly consumption, but it only gave 20·7 candles. The Stobwasser mantle, under similar conditions, gave 24·1 candles, and Kramme's mantles 37 candles. The superiority of the Auer mantle, after being used for some time, is also still more apparent. Tests were also made with pressures varying from $1\frac{1}{10}$ to $1\frac{2}{10}$ inch, and it was found that the effective values of all the mantles decrease with increased pressure, the loss with the Kramme being 7 per cent., with the Auer 10 per cent., with the Stobwasser 15 per cent., with the Benas 16 per cent., and with the Trendel 19 per cent. It is also to be observed that the glass cylinders of the Auer burners do not become so dirty as those with the other mantles, and the risk of breaking the mantles is increased the more frequently the cylinders are removed for cleaning. In every respect, therefore, the Auer mantles appear to be superior to the others experimented with. It might, however, be contended that the red and yellow rays of the other mantles are preferable to those of the Auer; but, if this is the case, it would be better to keep to Argand burners, as instead of paying a high price for the delicate incandescent mantles, with the use of which the cylinders become rapidly dirty, it would be preferable to retain the old style of lighting with durable burners and less dirty chimneys, more uniform illuminating power and less consumption for the same amount of light. C. G.

The Preparation of Acetylene, and its Use as an Illuminant and for the Production of Alcohol, &c. By Dr. FRANK.

(Verhandlungen des Vereins zur Beförderung des Gewerbfleisses, 1895, p. 20.)

Reference is made to the manufacture on an extensive scale, by means of the intense heat of the electric arc, of calcium carbide, a substance known as long ago as 1836 from the investigations of Wöhler, who obtained this product by heating carbon with an alloy of metallic calcium and zinc. Calcium carbide treated with water leads to a twofold decomposition: 64 parts by weight of the solid and 18 parts by weight of water, by their mutual reaction produce 56 parts by weight of quick lime and 26 parts of acetylene gas. Moissan[1] in Paris, and Thomas L. Willson, of the Spray Aluminium Manufactory, North Carolina, turned their attention independently to the preparation of calcium carbide by the use of the electric arc and both of them obtained successful results, the experiments of the former being mainly directed towards the scientific aspect of the subject, while the latter chemist from the outset turned his investigations to practical account and patented his process in 1893 for the production of an illuminant under the auspices of the Electric Gas Company.

Willson, who is confirmed in his results by Dr. Wyatt, maintains that with 1,200 lbs. of coal dust and 2,000 lbs. of powdered quicklime he obtains in the electric furnace in twelve hours, and at the expenditure of 180 electric HP., 2,000 lbs. of calcium carbide, the short ton (2,000 lbs.) thus costing for power, labour, and materials, $15. The Author analyses these figures and asserts that in the coal districts of Upper Silesia and Westphalia, with an abundance of cheap fuel, it would be readily possible to achieve similar results.

The cost of manufacturing 1,000 kilograms of calcium carbide in Upper Silesia is set down as follows:—

	Marks.
600 kilograms of coal-dust	12
1,000 „ „ powdered quicklime	18
200 electrical HP. for 12 hours at 1 kilogram of coal per HP. per hour, equal to 2½ tons of coal, together with engine and furnace	28
Labour	12
Total	70

Making the cost of the 2,200 lbs. of calcium carbide 70*s*.

From 2,000 lbs. of the calcium carbide Dr. Wyatt states that a yield of 10,590 cubic feet of acetylene gas can be obtained, and the gas, in consequence of its large percentage of carbon (92·3 per cent.), has a relatively very high illuminating value. For practical purposes it may be mixed either with atmospheric air, in which case it yields a very explosive and unsafe compound, or better, with coal gas of low illuminating power. Willson employed the

[1] Minutes of Proceedings Inst. C.E., vol. cxvii. p. 491.

latter diluent and obtained from the above volume of the gas 100,000 cubic feet of mixed gas of from 22 to 25 candle-power, which compares very favourably with the 16-candle gas in common use. Pure acetylene may, as Prof. Lewes has shown, be consumed with specially constructed burners and has an illuminating power equivalent to 240 normal candles, or about fifteen times that of common coal gas. It is assumed for the purpose of comparison, however, that 1 ton of calcium carbide will yield as much light as the gas evolved from 10 tons of coal. Various facts are collected in support of this contention, and the Author also considers the question of enriching poor gas by means of benzole—a plan which has lately been successfully adopted. It is possible to produce this fluid by passing acetylene through heated pipes, by which means three equivalents of acetylene (C_2H_2) are condensed into one equivalent of benzole (C_6H_6). By the process of Bunte 4 to 5 grams of benzole, when evaporated into 1 cubic metre of coal gas, enrich the latter to the extent of one normal candle-power. As 100 litres of acetylene gas weigh 116·5 grams, and as in their percentage composition acetylene and benzole are identical, it follows that a mixture of 100 litres of acetylene with 900 litres of non-illuminating gas will yield a light equal to that furnished by 1 cubic metre of 22-25 candle gas (116·5 grams divided by 4·5 grams = about 25). This coincides fairly well with the facts set forth by Willson and Wyatt. It is pointed out, moreover, that a given volume of acetylene gas for equal lighting effect evolves less heat and produces far less carbonic acid gas than common coal gas. These figures are contrasted with the cost of gas in Berlin, together with the value of the by-products, and the calculation shows a considerable margin of profit in favour of the acetylene gas. The Author maintains that, in the contest with the incandescence burner and electric light, these figures have an important bearing, while from the economical point of view, and that of the rapid exhaustion of existing coal fields, the great saving in coal effected by this process (as much as two-thirds) deserves careful consideration. The portability of the calcium carbide and the ease with which it may be cast into moulds of any required form point to its future use for lamps and for railway carriage lighting. In treating of its poisonous properties, it is alleged that its disagreeable smell is a great safeguard, and it is less dangerous than carbonic oxide gas, which already exists in many samples of coal gas to something like a similar extent that the acetylene gas would be used if it formed one-tenth of the volume of the illuminating gas. It is further asserted that calcium carbide may ere long be probably employed with advantage for alloying purposes and for conveying carbon to other metals. In this respect its use in the manufacture of steel has great possibilities.

In conclusion, the Author considers the ease with which acetylene may be converted into oxalic acid and acetic acid, and he shows also that under simple processes known to the chemist the gas may serve for the preparation of ethylene. This product when

passed into sulphuric acid yields sulphuric ether, and this latter derivative when distilled with water is decomposed into alcohol and sulphuric acid. Calculations follow respecting the yield of raw spirit from potatoes, and the Author suggests that calcium carbide may even furnish a source of alcohol which will hereafter compete with that made from potatoes.

G. R. R.

The Relief Line over the Giovi Pass.

By L. Capello and G. Giachino.

(Il Politecnico, 1894, pp. 3, *et seq.*; 1895, pp. 21, *et seq.*)

The railway from Genoa to Turin, commenced in 1846, and opened throughout in 1853, traverses the ridge of the Apennines between Pontedecimo and Busalla, having a maximum gradient of 1 in 28½. The celebrated Giovi tunnel, which carries the line under the summit of the pass, is 10,693 feet in length, and has a ruling gradient of 1 in 34½. The line was originally intended for rope traction, though finally constructed for working by very powerful locomotives; but its use was very limited, as with three engines to each train, not more than an average of 800 wagons or trucks could be worked over the line in a day. With the great development of the port of Genoa, it became an urgent matter to increase the facilities of inland communications. Various projects were studied; and finally a loop or relief-line was constructed from a point near the Genoa terminus, to a junction with the old line beyond the northern end of the Giovi tunnel.

The new line leaves the old main line at the station of Sampierdarena, and crossing the Torbella and Polcevera follows the northern slopes of this valley as far as Ponterosso; the heavily undulating ground necessitating a constant succession of viaducts and tunnels. At a distance of five miles, the valley is crossed by a masonry viaduct of two tiers of arches, 1,414 feet long and 190 feet maximum height. At Mignanego the gorge of the Ricco is extremely narrow, so that the station is built over the stream on a culvert 600 feet in length. At this point the old and new lines are separated by only a few yards, and at the same level, so that a junction can be formed if ever required. Immediately beyond this station the line enters the del Ronco summit tunnel, 25,580 feet in length. In order to secure protection from the irruption of water from the bed of the Scrivia, the tunnel is planned throughout on the western slope, the strata dipping eastward. At the further end of the tunnel is the station Ronco-Scrivia, at a height of 1,064 feet above the sea, this being the summit-level. From this point the descent of the Scrivia valley is commenced, the length to the junction with the old line being 13 miles 71 chains. The sharpest curves on the line are 20 chains radius, but the ruling radii are from 30 to 100 chains. The steepest gradient is 1 in 62½; the rate of inclination through the Ronco tunnel being 1 in

83½. There are sixty-six bridges, aqueducts and covered ways; twenty viaducts, having a total length of 9,956 feet; retaining walls 15,421 feet in length; and twenty tunnels, of which the nineteen exclusive of the Ronco have an aggregate length of 14,531 feet. The line is double, and laid to standard gauge.

The contract for the Ronco tunnel was let in November 1882, and the work was to be completed by March 1885. It was intended to drive headings from eighteen faces, but this number was curtailed, and work concentrated on three points. Work had proceeded for some months when it was discovered that the nature of the ground did not at all correspond with the estimates based upon preliminary investigation; and that instead of being solid and compact rock, the headings had to traverse disintegrated argillaceous schist heavily saturated with water. Fresh modifications were therefore necessary, and the time of completion was extended to about two years later. Mechanical boring was introduced, and hydraulic lime was employed. Energetic progress was made during the next year, when about 18,000 feet of heading had been driven and 11,000 feet of the tunnel completed; but heavy movement of the strata occurred, causing distortion of the section, and complete destruction in several places. Difficulties arose between the contractors and the Government, and the works were suspended for more than six months, with the exception of the necessary pumping. The contracts were then again re-adjusted, the finished section of the tunnel was considerably modified, and the work recommenced, and finally, after many difficulties involving minor variations, completed after the lapse of nearly seven years.

The Authors enter very fully, in an extensive series of articles, upon every detail of the construction of the tunnel, as well as giving descriptive accounts of the surface works at each shaft, and statistics of material and labour.

The headings were finally driven from eight points, namely:—

South end (Ponterosso) = No. 1; shaft No. 2; shaft No. 3.

Inclined shafts at Busalla = No. 4; shaft No. 7; shaft No. 8.

"Finestra della Pieve" (inclined shaft) = No. 9.

North end (Ronco) = No. 10.

The surface works at each of these points are described *in extenso*, buildings, machinery and *personnel*, with all the equipment for the various systems of boring adopted, and the barrack and infirmary arrangements provided. The greatest length driven from one point was from the Busalla shaft, viz., 5,984 feet; and the shortest from shaft No. 7, 1,289 feet.

In the Ponterosso heading mechanical boring on Brandt's system was adopted, the explosive being Nöbel No. 1 (Avigliana) dynamite, containing 75 per cent. of nitro-glycerine. The average quantity of dynamite used was 0·48 lb. per cubic yard, and the maximum quantity 2·3 lbs. The tunnel section was completed in short lengths, and the nucleus of the rock was not removed until everything was ready for the construction of the invert. Ventilation was effected by Scheele's apparatus, two ex-

hausts coupled; 3,300 feet of the tube being 15¾ inches diameter and the remainder 11¾ inches. The strata at the southern end of the tunnel are much disintegrated, so that exceptional difficulty was experienced. Towards the northern end the formation is calcareous, and considerably more compact. At No. 2 shaft the explosive used was No. 1 Cenzio dynamite (guaranteed 78 per cent. of nitro-glycerine), the quantity averaging 0·54 lb. per cubic yard.

At Busalla advantage was taken of the configuration of the pass to work from two inclined galleries, instead of from a vertical shaft. These, which were 932 feet in length and with an inclination of 1 in 3·12, greatly facilitated the work. An attempt was made in the headings from this point to use the electric-light, but this was not attended with success, the chief drawback being the restricted area lighted in the limited height and thick atmosphere, and the heavy shadows amongst the timbering. Various systems of construction were adopted in different sections, according to the nature of the ground. At the Ronco end and at the Finestra della Pieve the so-called "Belgian" system was employed, the top heading being first driven and the crown of the arch constructed, then the side-walls and springings, and finally the invert. The system followed at the southern end—at Ponterosso and Busalla—was that known on the work as the "English" method, the first heading being at formation level, the second at the crown, the side-walls being built in independent lengths. At the four vertical shafts a mixed system was adopted, partaking of the characteristics of both the preceding methods. Mechanical boring with compressed air was employed at Busalla, and at shafts 2 and 3, the Ferroux drills being used, while the Brandt system was worked at Ponterosso. The following is a brief statement of the work done at the various shafts:—

——	Busalla (Two Headings).	No. 3.	No. 2.	Ponterosso.
System of boring adopted . . .	Ferroux	Ferroux	Ferroux	Brandt
Duration of observations . days	364	168	168	280
Number of blasts	667	285	225	515
Average number per diem . . .	1·67	1·70	1·33	1·33[1]
Total length of heading bored . . . . . lineal ft.	2,909	1,394	1,014	2,251
Progress per diem . . „	7·87	8·30	6·04	8·04
„ per blast . . „	4·26	4·89	4·49	4·36
Time for each blast	H. M. 14 21	H. M. 14 9	H. M. 17 48	H. M. 13 2
Number of machines at each face .	4	4	4	2
Number of drills	19	25	29	17
Mean depth of holes . lineal ft.	4·89	5·38	5·32	4·99
Mean charge of dynamite per hole . . . . . lbs.	1·247	1·668	1·637	3·41
Dynamite used	Cenzio No. 1	Cenzio No. 1	Cenzio No. 1	Avigliana No. 1

[1] *Sic* in original. 1·84 is probably meant.

The following tabular statement gives a summary of the work done from the several shafts or faces:—

Working Point.	Length of Tunnel Constructed.	Amount of Excavation.	Amount of Masonry or Brickwork.	Total Duration of Work.[1]	Average Progress of Completed Section per Diem.	Consumption of Dynamite per Cubic Yard of Excavation.
	Lineal Ft	Cubic Yds.	Cubic Yds.	Days.	Lineal Ft.	Lbs.
South end (Ponterosso)	5,505	182,119	74,108	821	4·89	0·48
Shaft No. 2 . . .	1,703	55,507	20,436	409	3·05	0·54
„ No. 3 . . .	2,772	84,355	31,470	407	4·59	0·61
Busalla shaft . . .	5,984	201,574	76,574	883	6·07	0·50
Shaft No. 7 . . .	1,289	33,312	12,657	256	4·17	0·52
„ No. 8 . . .	3,067	87,744	26,661	224	3·87	0·51
Finestra della Pieve .	3,281	93,396	28,563	308	4·03	0·59
North end (Ronco) .	1,979	55,248	18,804	218	2·26	0·68

In summarising their observations upon the various systems of construction and the results obtained, the Authors remark that the mechanical boring and blasting was not attended with success, the strata being so deficient in cohesion that it suffered greatly from the disintegrating effects of the continued concussion. In the "Belgian" system of working, the distance between the various parts of the work—the crown to the side-walls—in ordinary lengths of section allowed too much play to the shifting strata; while in completing the section with contiguous headings, progress was limited by the facility of clearing the material, so that in this case also the ground was frequently set in movement. The mixed system was practically the same as the Belgian, only in shorter lengths. The subjoined table shows the relative progress made, and the portions requiring reconstruction after disruption. The exceedingly difficult nature of the work at the southern end of the tunnel is conspicuously evident by the figures.

Working Point.	System of Construction.	Average Work in Twenty-four Hours.		Proportion of Finished Work requiring Reconstruction.
		Excavation.	Brickwork.	
		Cubic Yards.	Cubic Yards.	Per cent.
South end (Ponterosso) . .	English	220	87	62·5
Shaft No. 2	Mixed	104	30	29·8
„ No. 3	„	191	74	1·4
Busalla shaft	English	313	105	17·7
Shaft No. 7	Mixed	138	46	..
„ No. 8	„	116	40	..
Finestra della Pieve . . .	Belgian	164	52	0·2
North end (Ronco)	„	99	25	..

It was originally proposed to construct the tunnel in masonry;

[1] This includes work in sinking the shafts and surface work.

but it soon became evident that it would be impossible to obtain sufficient material within reasonable or economical distance. The masonry work actually carried out was therefore limited to the lengths constructed from the Ronco end, Finestra della Pieve, and shaft No. 8. The rest was executed in brickwork, the materials being obtained as follows:—

From Arquata	38,919,000
„ Ronco	10,880,000
„ Alessandria	12,253,000
„ Valenza	11,869,000
„ Serravalle	5,175,000
„ Cantalupo	2,329,000
„ Solero	686,000
„ Tortona	1,126,000
Total	83,237,000

The mortar originally intended to be used was to be mixed in the proportion of one part of Casale (hydraulic) lime in paste to two parts of Scrivia sand. The latter material was, however, found not to be suitable, as it did not allow of setting well or quickly. The proportion was varied to 0·45 of lime, 0·70 Scrivia sand, and 0·20 pozzolana; but towards the end the Scrivia sand was abandoned, being replaced partly by sand from Bormida and partly from the sea.

P. W. B.

Four-Cylinder Compound Locomotives. By C. Baudry.

(Revue générale des Chemins de fer, November 1894, p. 243.[1])

The Author gives further particulars of the type of four-cylinder compound locomotives brought into service on the Paris-Lyons and Mediterranean Railway in 1893. These locomotives, with eight wheels coupled of 4·92 feet diameter, are principally used for goods trains on the main line from Paris to Marseilles, and for passenger and mixed trains on some heavy lines. The normal speed is between 22 miles and 28 miles an hour, the maximum speed is fixed at 40⅓ miles an hour.

The new locomotives are compared with the non-compound engines of 1881 and the compound-engines of 1888, and tables are given showing side by side the dimensions of the three types, together with Plates giving diagrams of each. Similarly to the 1888 engines the steam passes directly from the boiler to the high-pressure cylinders, from these it proceeds to the low-pressure cylinders. The four valves actuated by the "Walschaert" gearing are reversed by one steam-controlled mechanism, which ensures a proper relationship between them, independent of the

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[1] Minutes of Proceedings Inst. C.E., vol. cxiii. p. 433.

engine-driver, for each position of the lever. A special cock allows the engine-driver to send the steam direct from the boiler into the intermediate steam-chest between the high-pressure and low-pressure cylinders, for starting only, and without the steam leaving the high-pressure cylinder and escaping to the air; a spring safety-valve placed on the chest and communicating with the air prevents the pressure rising above 100 lbs. per square inch. The description of the Serve-tubes used was given in the previous article.[1]

In comparing the consumption of fuel it was found that there was an average of saving in the 1888 type, compared with the non-compound type of 1881, of 10·5 per cent. In comparing the new engines with those of 1881 an average saving of about 13·5 per cent. was found.

The following are the principal dimensions of the new engines:—

Weight	49·08 tons.
„ in working order	52·85 „
Interior diameter of the boiler-shell	4·59 feet.
Steam-pressure	213 lbs. per square inch.
Number of tubes	139
Length of tubes	9·84 feet.
Exterior diameter of tubes	2·56 inches.
Heating surface of tubes (interior)	1,555 square feet.
„ „ of fire-box	105 „
Total heating surface	1,660 „
Grate area	26·47 „
Diameter of cylinders (high pressure)	14·17 inches.
Diameter of cylinders (low „)	23·23 „
Stroke of piston	25·59 „
Number of cylinders	4
Diameter of driving-wheels	4·92 feet.
Wheel base between extreme axles	18·80 „
Total length of engine	32·05 „
„ width of engine	9·19 „

The Paper is accompanied with plates giving detailed plan and sections of the new locomotives.

J. A. T.

Traction by Fireless Locomotives. By J. Deffoux.

(Bulletin de la Société Scientifique Industrielle de Marseille, 1894, p. 85.)

The Author states that the construction of a line of railway from the heart of the city of Marseilles to the great necropolis in the quarter of St. Pierre became an absolute necessity. Eventually a scheme was adopted and the line constructed and opened early in 1894. The line is 1·86 mile in length, and the difference in level between the termini is 87·9 feet.

At the commencement there is a tunnel 798 yards in length,

[1] Revue générale des Chemins de fer April 1893; and Minutes of Proceedings Inst. C.E., vol. cxix. p. 443.

built on gradients varying between 1 in 25·64 and 1 in 30·48; the tunnel is for a double line of way, having a width at springing of 21·33 feet, and a height above rail at the crown of 15·75 feet. The gradients for the remaining portion of the line vary between the limits of 1 in 286 and 1 in 31.

Vignoles rails are used in the tunnel and on that portion of the line which is laid away from the roads. Where the line runs through the streets—which happens in two places—the rails employed are of the Marsillon type. The weight of the Vignoles rail is 49·39 lbs. per lineal yard.

The chief feature of the line lies in the fact that fireless locomotives are used. The "Francq" system is adopted, in which there are two distinct parts, as follows: 1st, a generating station in which the generators which produce the steam necessary for the reheating of the water in the receivers of the locomotives are fixed; 2nd, the locomotives.

The Generators.—At the station there are three generators, of which two are constantly in use, the third being in reserve. The boilers are of the locomotive type, with rectangular fire-boxes and Berendorff tubes, having a large water and steam reservoir on the top with a steam dome.

The principal dimensions are as follows:—

Steam-pressure	227·5	lbs. per square inch.
Number of tubes	44	
Length between the tube-plates	16·4	feet.
Exterior diameter of the tubes	2·75	inches.
Heating surface of fire-box	65·66	square feet.
„ „ of tubes	497·42	„ „
Total heating surface	563·08	„ „
Grate area	11·63	„ „
Mean interior diameter of the boiler	35·43	inches.
Volume of water about	682	gallons.
Volume of steam about	77·69	cubic feet.

The steam from each generator, by means of a valve, can be distributed into several filling appliances. The feeding appliances are composed of two Friedmann injectors of 0·157 inch.[1]

The Locomotives.—These consist essentially of a cylindrical receiver charged with warm water at the maximum pressure of 227·5 lbs. per square inch. When at the end of their course the pressure has descended to from 43 lbs. to 71 lbs. per square inch, the water is reheated by means of a current of steam provided by the generators.

The generators are put into communication with the engine receivers in the following manner:—The engine is brought on to a loading pit in front of the steam valve. The steam-pipe of the generators communicates with the receivers by means of an intermediate pipe in the form of a swan's neck to give it more

[1] A second appliance has recently been added, comprising two Friedmann injectors of 0·236 inch, and one Sellers of 0·295 inch, which are arranged so that one or more generators may be supplied separately or simultaneously.

elasticity; the latter is fixed on one side to the filling conduit by a Mesnard and Francq appliance called a discharging regulator, and on the other side to the receiver by a nozzle having a screw with a very strong thread which, by means of a lock-nut, makes a provisional and solid joint with the cock placed on the warm-water receiver. The discharging regulator regulates automatically the delivery of the steam in such a manner that the reheating of the water in the interior may be made progressively until the temperature attains 203° C., corresponding to a pressure of 227·5 lbs. per square inch. The steam coming from the boilers is admitted into this regulator by means of a flap valve between two equilibrium valves, fixed to a piston on which a spiral spring acts.

The warm-water receiver is cylindrical, with a steam-dome. Its interior diameter is 3·77 feet, and its total interior length 10 feet. The cubical content of the receiver without the dome is 105·95 cubic feet, the volume of warm water being 550 gallons, and the volume of steam about 21·19 cubic feet. The steam coming from the generators is introduced through the cock to a longitudinal tube in the lower part of the receiver, pierced with holes so arranged that the steam is equally distributed in the mass of water and the temperature of the whole is kept even.

The expansion gear (Francq and Mesnard system) consists of two valves connected together, and of the same diameter, in order that they may equalise themselves under the variable pressure of the steam of the receiver. These valves are controlled by the action of a spring balance by means of a curved lever and a piston provided with a rubber diaphragm. The piston receiving directly the pressure of the steam which passes away by the valves, the pressure can be made to vary instantaneously by a simple displacement of the action of the balance on the lever, the limit of variation being about 42 lbs. per square inch. This condition is indispensable for heavy gradients or difficult starting points. The gear, further, is provided with an ordinary throttle-valve.

The escaping steam is conducted into a condenser with vertical tubes placed above the receiver. The condenser consists of 1,154 tubes representing a cooling surface of 538 square feet. The water is collected in a box placed at the back of the engine. One of the conditions imposed was to avoid absolutely all escape to the air of smoke and steam, and even of an excess of water in the tunnel, and the Author states that these engines have admirably fulfilled the condition. The receiver is protected against cooling by a case of thin metal, a layer of air being thus imprisoned between them, and also by another case, the interior of which is lined with a calorific substance, for which in this case silicate of cotton has been used.

The cylinders of the locomotives are placed outside the frame; the locomotives have four wheels coupled; the motion consists of two cylinders coupled at 90°; the gearing is on the "Walschaert" system, and the mechanism is placed as much as possible under cover. The weight of the engine is about 9 tons, or 12 tons

loaded. The gauge of the line is 3·28 feet, and the following are the principal dimensions of the locomotives:—

Diameter of the cylinders	9·84 inches.
Stroke of the piston	11·81 „
Diameter of the wheels	27·58 „
Wheel base	4·26 feet.
Total length	15·26 „
Thickness of the tires	1·97 inch.
Diameter of the wheels without the tires	23·62 inches.
Maximum width	6 89 feet.
„ height above the rail	10·49 „

The average weight of the carriages used is about 4·37 tons, which gives a dead weight of 187 lbs. per passenger, a result which the Author believes has never been attained previously in mechanical traction. The carriages are divided into two compartments by a central gangway, and have longitudinal seats, leaving at each end a very large and spacious platform. Each carriage holds fifty-two passengers, namely, eight in the first class, sixteen in the second class, and fourteen on each platform. The carriages are mounted on four wheels, on the Beynès simple bogie system, which enables them to traverse easily curves of one chain radius.

The principal dimensions are as follows:—

Exterior length of the compartments	19·68 feet.
Length of each platform	5·41 „
Total length of the carriage	29·53 „
Maximum width	6 89 „
Wheel base	14·11 „
Diameter of the wheels	27·56 inches.

The engines and carriages are provided with hand and vacuum brakes, the latter being on the "Soulerin" system.

Owing to the existence of the tunnel it was necessary to have the carriages lighted, and with a view to be able to turn the lights on and off on the entrance to and departure from the tunnel electric lighting was adopted. The "Fulmen" accumulators are used on account of their small weight and size; twelve accumulators are placed in each carriage, arranged in four cases containing three each; each case weighs 44 lbs.; thus the total weight for each carriage is only 176 lbs. The battery provides for four lights for sixteen hours.

The trains are composed of an engine and two carriages, and on week-days a service of fifty trains is run in each direction; on Sundays and holidays the number is increased to sixty-two. Each journey is performed in eighteen minutes, the maximum speed allowed being 12½ miles an hour. There are seven stations between the termini.

In conclusion, the Author states that the system of traction adopted has given every satisfaction, and can be advantageously compared with other systems.

Three plates accompany the Paper. J. A. T.

Direct-coupled Bogie Frames for Railway Carriages.

By J. Buch.

(Organ für die Fortschritte des Eisenbahnwesens, 1894, p. 212.)

This system, called the Schmidt-Bell system, has been introduced with a view to facilitate the running over sharp curves, and consists essentially in fixing the buffers and couplings directly on to the bogie frames. By this means the locking of the buffers together is avoided and sharp curves can be safely and easily traversed. The Author illustrates and describes the system as applied to long passenger or sleeping carriages.

At a short distance from each end the bogie frame is bent upwards in order that the buffers and couplings may be at the normal level of the under-frame of the carriage. The draw-bar is attached to the centre of the under-frame in the ordinary manner, and is slotted and flexibly jointed at the pivot to allow for the independent motion of the bogie. The weight of the carriage is transmitted to the bogie frame through the pivot by means of a suspended girder supporting six transversal springs. The under-frame is of such dimensions as to allow sufficient clearance for the bogie frame in traversing sharp curves. A diagram is given showing the angles which the under-frames and bogies of two carriages coupled together will make with each other on a sharp curve, illustrating the advantages to be gained by this method.

The Author states that the chief advantages of this system are the following:—

1. The rapidity with which the bogies adapt themselves to sharp curves.
2. Lessening the liability to derailment.
3. The ability to use carriages of great length on sharp curves.
4. Reduction of tractive force.
5. Reduction of the wear and tear of tires and rails.

A plate is given with plan and sections of the bogie frame.

J. A. T.

Heating of Railway Trains by Steam and Compressed Air Combined. By — Lancrenon.

(Bulletin de la Société d'Encouragement pour l'Industrie Nationale, January, 1895, p. 17.)

The system of heating trains by means of steam and compressed air combined has been tested, and is now being applied by the Eastern Railway of France. In studying the working of steam-heating appliances, the Author had been struck with the difficulty with which a sufficient pressure is obtained in the general conduit at the extremity of long trains. To overcome this, he decided to

endeavour to obtain a more regular pressure by adding to the steam a non-condensing fluid, such as air. Numerous experiments were made on test-trains, and finally the system is being applied to the regular trains.

The principal effect of air added to steam appears to be the sweeping away and continual movement of the water of condensation which tends to accumulate at the low points of the conduit and at the evacuation orifices, thus avoiding the accumulation of water and the danger of freezing. With the addition of air, the study of the most convenient arrangements to adopt for the heating appliances is simplified and facilitated. The evacuation of the condensed water from each vehicle is assured. Much smaller tubes—of the most varied forms—can be used without the necessity of arranging falls in order that the drainage of the water can always be made by gravity. From the calorific point of view, the mixture gives in practice results which differ very little from those of steam alone at the same pressure. The quantity of air added and the difference of temperature which results are not of such a nature as to modify, to an appreciable extent, the calorific effects.

The appliances consist of a general conduit from the engine, into which the engine-driver sends the mixture of air and steam. This conduit runs through the whole train and terminates in an automatic expansion blow-off cock, which allows the condensed water and chilled air to escape, but retains the steam. At each vehicle, a convenient number of heating tubes branch off from the general conduit, pass through the compartments, then re-unite again to meet in one blow-off cock. Admission cocks enable the steam to be admitted into one or more of the tubes. The dimensions of the general conduit have been determined in order that trains of fifteen to eighteen vehicles may be heated, and at the same time to keep it as small as possible in order that the double advantage of having more durable and manageable couplings, and of increasing the speed of the gaseous current, may be obtained. The latter ensures the avoidance, as much as possible, of accumulations of water. The conduits used are 1·77 inch in exterior diameter, except at the couplings, where they are 1·38 inch in diameter. The coupling tubes are made of india-rubber similar to the brake tubes. In the coupling, care has been taken not to have too sharp angles, this arrangement being essential for conduits in which a double current of gas and liquid circulates.

Two arrangements have been adopted on the engines. On powerful engines, destined to draw long trains, one pump alone does not suffice for the brake and heating service, and therefore a second pump has been fixed for heating purposes alone. The steam of the boiler by its expansion compresses the air, then it is afterwards utilized for the heating. The delivery of the pump is regulated by means of an admission cock. A steam-valve on the boiler, a safety-valve, and a steam-gauge complete the appliances on the engine. On engines for drawing light trains, the

composition of which does not consist of more than from eight to ten vehicles, the special pump for heating purposes is suppressed and the heating appliances comprise only a steam-valve on the boiler, an air-valve on the delivery-pipe of the brake air-pump, a safety-valve and a steam-gauge. In both types, the safety-valves are regulated to 42·66 lbs. per square inch.

In the vehicles the main objects have been to heat the feet of the passengers, and to avoid all contact between the air of the compartments and the tubes heated directly by steam, in order to exclude any bad odours. In the second- and third-class carriages three heating tubes branch off from the general conduit at one of the ends of the carriage; these run side by side through each compartment under the feet of the passengers; over them and flush with the floor are placed perforated plates, which they heat and which form foot-warmers. In order to avoid a too close contact and a too high temperature of the foot-warming plates, hoops of 0·039 inch in thickness are interposed between the tubes and the plates. In leaving the last compartment, the tubes reunite to meet in an automatic blow-off cock. Admission cocks, manipulated outside the carriage, allow the mixture of air and steam to be sent at will into one, two, or three tubes; in this way the heat is regulated and is necessarily the same for all the compartments of the same vehicle, and the Company's men alone can interfere with the regulation of the heat.

In the first-class carriages an independent heating appliance has been provided for each compartment, and the regulation of the heat is at the disposal of the passengers. There are two heating tubes for each compartment branching off from the general conduit, then passing under the floor, with foot-warming plates arranged as in the second- and third-class compartments, and then meet in a collecting tube, common to all the compartments, which terminates in an automatic blow-off cock. The admission cocks can be manipulated either inside by the passengers, or outside by the Company's men. The foot-warming plates are of brass, and, on account of its greater conductivity, it gives with two tubes almost the same heat as iron plates with three tubes.

A third arrangement, quite different, has been adopted for the Imperial carriages used for the Paris suburban traffic. The general conduit branches off at each carriage into two pipes which pass along each side of the roof compartment. A tube, governed by a stop-cock and only closed in case of damage, branches off from the neck of the conduit, and descends to the lower compartments; passing through them in the same way as already described for the ordinary carriages. No regulation is possible for separate carriages, but the engine-driver can heat the whole train either continuously or at intervals of a shorter or longer duration.

In describing the automatic blow-off cock placed on the carriages and at the end of the general conduit, the Author states that the problem to be solved was to find an apparatus which would only allow the condensed water and corresponding air in

the conduits to escape, and would close as soon as steam of a certain amount arrived at the orifice, whatever the pressure in the conduits was. Such a result can only be obtained by means of an appliance working by the expansion of a liquid not changing into steam at the temperatures reached. For this purpose purified "oléonapthe" has been chosen. This liquid is enclosed in a tight metallic capsule, and terminates by metallic bellows in the form of a Venetian lamp, which stretches out when the liquid expands. The capsule is enclosed in a case fixed to the end of the tubes. When steam gets into this case, the liquid expands, the bellows elongate themselves and close the opening placed at the extremity of the case. When, on the contrary, the case contains only water or air, the liquid and the bellows contract and open the valve, which then allows the water and air to escape. These appliances now work with great regularity and without danger of obstruction by ice, even when the temperature is as low as 0° F., this result being due to the use of compressed air.

The heating apparatus described, has already been fixed on 562 carriages, and 229 engines. The Author states that they have given every satisfaction, and compares this system to the other systems in use, namely, the ordinary foot-warmers (containing warm water simply, or with acetate of soda), the slow combustion stove system, the thermo-siphons, the Belleroche system of warm-water pipes, and the steam-heating system, all of which he describes in detail. The heating plates in each compartment are 9·84 inches in width, and 8·20 feet long; when the three tubes are in use the temperature of the plates rises to 140° or 150° F.

The time necessary in order that the steam may arrive at the rear of the trains varies as follows:—

Train of twelve carriages	8 to 10	minutes.
,, fifteen ,, ...	12 ,, 16	,,
,, eighteen ,, ...	15 ,, 20	,,
,, twenty-four carriages. . .	28 ,, 35	,,

Five minutes must be added to these times in order that the foot-warming plates may attain a temperature of about 122° F. The weight of the appliances is on the average one half of a ton per carriage. The cost of applying the system is about £60 each for the engines destined to draw the heaviest trains, and from £16 to £20, according to the types, for the engines destined to draw the light trains, and from £32 to £36 each for the second- and third-class carriages, and from £48 to £52 for the first-class carriages, according to the number of compartments. The actual cost of the heating does not surpass 0·3*d.* per carriage per hour. With regard to the couplings, experiments are being made with metallic couplings with a view to using them in place of india-rubber if satisfactory results follow.

Several plans and sections accompany the Paper.

J. A. T.

The Injection of Sleepers in France.

By — EUVERTE.

(Revue Générale des Chemins de Fer, p. 90, 1895.)

The Author states that there are two conditions essentially necessary in order that an antiseptic may produce a useful result in the preservation of sleepers, namely, its liquid state at the moment of injection, and a reasonable cost. Sulphate of copper, chloride of zinc, and creosote fulfil these conditions. Sulphate of copper is rarely used at the present time; chloride of zinc is largely used in Germany, Austria, and Russia, and creosote has for a long period been used in England, Belgium, France, Austria and Portugal, having the advantages of a low price, and of the fact that the naphthaline becomes insoluble and remains imprisoned in the fibres of the wood. On the State Railways of France a mixture of creosote and chloride of zinc is used in the proportions of thirty-one parts of chloride of zinc and forty-six parts of creosote to 1,000 parts of water.

The Author describes the manufacture and qualities of creosote, and states that a good creosote should contain at least 10 per cent. of naphthalene (and not more than 30 per cent. to avoid choking), as much as possible of phenol (10 per cent. may be admitted), and it is also advisable for it to contain a good proportion of anthracene oil.

On French lines oak, beech, or pine sleepers are generally employed, and exceptionally fir, larch, and chestnut. An oak sleeper absorbs on the average from 8·8 to 12·3 pints of creosote, whilst beech or pine sleepers will absorb about forty-four pints, but on account of the expense a less quantity is made to suffice for the preservation of the latter.

The following are the weights of creosote per sleeper adopted by the principal railway companies for the different kinds of wood:—

	lbs.	
Oak	11 to 15½	(The absorption limit.)
Beech:—		
Northern Company	28½	
Western ,,	33 to 35¼	
Paris-Lyons-Mediterranean Company	35¼	
Eastern Company	53	(The absorption limit.)
Pine:—		
Midi Company	26½	
Orleans ,,	31	
Paris-Lyons-Mediterranean Company	26½	

For the creosoting of the sleepers the Northern Company employs a special process which is a modification of the old Blythe system. It consists in submitting the sleepers to the action of superheated steam at a minimum temperature of 392° F., which has passed over a reservoir of creosote. The products of condensation containing water and creosote are then evacuated (the creosote after-

wards being extracted and used again), and the cylinder is filled with creosote and steam pressure is applied. The other companies use the ordinary vacuum and pressure process.

The general design of the sleeper depots and creosoting yards are fully described, as well as the operations of creosoting. With two fixed cylinders, each about 39 feet in length, and about 5½ feet in diameter, and each therefore capable of holding 128 sleepers, the daily output is 2,160 sleepers, or, in round numbers, 600,000 a year. Where movable cylinders are employed the output is about 30 per cent. less; these cylinders are mostly used by contractors on account of the facility with which they can be moved from place to place, and on account of the reduced first cost. The railway companies which do their own creosoting use fixed cylinders.

The average cost of creosoting per sleeper is, for oak, 8·64*d*., and for beech or pine from 1*s*. 3·5*d*. to 1*s*. 9·3*d*., according to the amount of creosote injected.

Five plates accompany the Paper, giving plans of various creosoting depots in France.

J. A. T.

Street-Railways worked by Gas-Engines.

(Archiv für Post und Telegraphie, p. 129, 1895. 2 Figs.)

In the first issue of the Archiv for the present year, the opening of a street-railway at Dessau on the 15th of November, 1894, was briefly alluded to. This railway is worked by gas-engines, and during the first three months' running has quite fulfilled expectation and proved satisfactory during the heavy snowstorms and severe cold. The Author considers that the future is promising for this class of railway, and gives details of the system invented by the late Mr. Lührig, of Dresden, in 1893, and first tried upon the line from Dresden-Neustadt to the Wilder Mann.

The first car had many defects, but most of these were remedied in a second car brought into use in March 1894. The trials of this car were so satisfactory that on the initiative of Mr. Oechelhäuser, a Privy Councillor of the Board of Trade, a street railway company was formed in Dresden for the purpose of exploiting the system. In England also the use of gas-engines on tramways is making progress, and an engine of this type has already been tried by the Croydon Tramways Company. In the case of the Dessau cars the engine is placed under one of the two seats. It has two horizontal cylinders, one placed upon each side of the driving-shaft. The space occupied by the engine is closed below, and has no connection with the interior of the car, but is accessible from outside by means of one large double door and two small falling doors.

When the doors are all closed, the only sign of the presence of

the engine is the semicircular-shaped door which affords access to the fly-wheel. Viewed from the other side, the car does not differ from those in use with horses or electricity. Nothing can be seen of the engine inside the car, nor is there a smell of gas, and the noise does not exceed that noticeable with a horse-car. There are three gas-reservoirs, two of which are placed parallel to the axles, and the other acts as a counterpoise for the engine.

The three reservoirs together hold 28·25 cubic feet of gas, which has at the beginning of the run a pressure of 90 lbs. per square inch. The cooling tank has a capacity of 66 gallons, and the water becomes so warm that there is no chance of its freezing, and it can be used to feed heating-coils inside the car. The speed is regulated by the driver, who also has the reversing-lever and brake-lever under his control, the latter lever being provided with a bell. Brake-tests show that at full speed the car can be brought to rest in 6 feet 7 inches. The gas-reservoirs can be filled in from two to three minutes, and contain sufficient for 6·2 miles. On both lines in Dessau a ten-minutes' service is in use, but a seven-and-a-half-minutes' service is to be substituted for it.

The service is appreciated by the public, and in this town of 42,500 inhabitants the number of passengers on the Post-Friedhof III section has never fallen below 600 per day, and has averaged 1000 per day upon the Bahnhof-Leopolddankstift section; it has been decided therefore to increase the length of the line. The efficiency of the motor has exceeded expectation, and it will not only drive a car containing fifty or sixty persons at the proper speed, but a tow-car also, which is made use of several times a day by a large cloth company for the purpose of sending parcels to the post; the number of these parcels reaches 450,000 per annum.

It is quite possible that as soon as the section Post-Bahnhof is finished the cars will be used for postal and telegraphic purposes also. The Author considers gas superior to horses, steam or electricity as a motive-power for street-cars; in the first case, owing to the absence of droppings, and accidents caused by shyings, and falls; in the second case, because, owing to the great weight of the locomotives, they can only profitably be used where trains of cars can be adopted; in the third case, because accumulators are not yet sufficiently perfect, underground systems of conductors are too costly and are liable to be deranged by snow.

In the case of overhead electrical lines also the cost is high, the streets are disfigured, and the working of the telephone and telegraph lines seriously affected. The Author refers to a fire which was caused by the high-tension wires in use on the Dortmund and Barmen lines. No special track is required for the gas-engines, and the compressing station causes neither smell, soot nor smoke. The 8-HP. engine works only three hours per day, and at its full capacity would suffice for 20 cars at a time, whereas about 200 HP. would be required for an electric line of the same capacity. The capital required for installation and the cost of

maintenance are both stated to be much lower for gas-power than for electrical power.

The only drawback that the Author is aware of is that at present the gas-cars will not mount gradients steeper than 1 in 20, but this difficulty will doubtless soon be overcome.

A company has now been formed in Dessau for the supply of the whole plant and rolling-stock required for street-railways worked by gas-engines.

E. R. D.

The Popp-Conti System of Pneumatic Tramways.

(La Revue Technique, May 10, 1895, p. 193.)

The chief characteristics of this system are: the use of compressed air at a moderate pressure (140 lbs. to 280 lbs. per square inch); small reservoirs on the cars; distribution of the compressed air by pipes under the road; special valves on these pipes, by means of which the car reservoirs can be semi-automatically refilled.

These valves are the chief peculiarity; their action is very briefly as follows:—The car-wheel flange presses down a pedal in the rail groove and actuates a hollow "knife" which rises from the air-main through a manhole in the roadway between the rails. The driver, without leaving the car, then opens a valve which makes the requisite connection with the "knife" and admits the air to the reservoir from the main. When the reservoir is full the driver closes his valve, the connection is broken, and the "knife" falls again below the surface of the roadway.

The motor is a two-cylinder compound engine, and the air is heated by a small coke fire, before entering both the high- and low-pressure cylinders. The trucks are four-wheeled, the two axles being coupled.

The following advantages are claimed for this system of mechanical traction: simple central station machinery (engines and compressors only); economy in road construction, the air mains and valves being inexpensive, simple and easily laid; economy in working, the load at the central power station being very uniform; and convenience in working owing to the ability to recharge the car-reservoirs at several points along the line without appreciable delay.

An experimental line has been constructed in Paris near the Champs de Mars. The article is illustrated by a plan of a central station for this system, photographic views of the several parts of the mechanism, and an ammeter diagram from the Marseilles electric tramway, to exemplify the great variation of load on an electric line.

R. B. M.

Recent Applications of Compressed Air. By Carlo Medina.

(Annali della Società degli Ingegneri e degli Architetti italiani, 1894, p. 255.)

The Author, in the course of a résumé on the employment of compressed air, classifies and schedules its present chief applications as follows :—

(1) Transmission to a distance from a central station—
  A. Power for mechanical industries, *e.g.*—
    Cranes, hoists and lifts;
    Lathes, pumps, injectors;
    Saw-mills, grinding mills, weaving and textile mills, &c.;
    Printing machinery;
    Foundries, iron and steel works, &c.
  B. Chemical industries:—Filtration, refrigeration, desiccation;
    Sugar refining;
    Gas purification, &c.
  C. Ventilation:—Schools, hospitals, barracks, theatres, hotels, houses, &c.
  D. Electric-light motors.
  E. Lifts and hoists in private buildings.

(2) Railways and tramways:—
  (*a*) Traction (by compressed-air motors).
  (*b*) Brakes.
  (*c*) Signals.
  (*d*) Points.
  (*e*) Level-crossing barriers.
  (*f*) Warming carriages.
  (*g*) Ventilation of tunnels.

(3) Foundations:—Pile sinking, mining and excavation—
  (*a*) Motive power;
  (*b*) Ventilation;
  (*c*) Expulsion of water and noxious vapours.

(4) Pneumatic postal transmission.

(5) Sanitary applications in towns and cities—
  (*a*) Ventilation;
  (*b*) Drainage;
  (*c*) Water purification;
  (*d*) ,, exhausting from wells and other receptacles;
  (*e*) ,, raising.

(6) Naval and military service—
  (*a*) Pneumatic guns;
  (*b*) Charging bombs and other projectiles;
  (*c*) Torpedoes;
  (*d*) Submarine boats;
  (*e*) Steering;
  (*f*) Forced draught.

(7) Surgery:—Application to various surgical instruments.

(8) Production of cold—
  (*a*) Ice making;
  (*b*) Refrigerators.

(9) Miscellaneous industrial appliances and processes, *e.g.*, preservation of timber, lubrication, &c.

P. W. B.

The Testing of Oil-Engines.

By Professors HARTMANN and SCHÖTTLER.

(Arbeiten der Deutschen Landwirthschafts-Gesellsschaft, 1894, part 6, p. 1.)

A trial of agricultural oil-engines was held by the German Agricultural Society in June 1894 at Berlin. Only engines working with an inflammable mixture of petroleum gas and air were admitted to the competition. Each engine was tested as follows:

1. With a brake (*a*) at full power for one hour; (*b*) at half power for one hour; (*c*) running empty for half an hour, and about five minutes at the maximum possible power. Indicator diagrams were taken at the same time. During these trials the consumption of petroleum, of lubricating-oil, and of cooling-water; temperature of the water in and out; efficiency; steadiness in running; variations of speed; and maximum power developed were determined.

2. While driving one or more agricultural machines with rope-transmission, when the following points were studied: Simplicity; time required to start; automatic regulation of the speed; accumulation of dirt after running for sixty hours; smoothness in working; time and labour required to clean the engine; noise, smell, inconvenience from the exhaust; and weight of the portable engines with special reference to the cooling-water used.

In awarding the prizes, the economy of the engine was calculated as regards: consumption of petroleum, of lubricating-oil, and water; also interest upon capital, and cost of repairs; the motor being supposed to run 1000 hours in the year.

The oil was supplied by the Society. American petroleum of 0·80, and Russian petroleum of 0·82 density were used indiscriminately for all the engines.

Since gas-motors are out of the question in the country, the development of portable oil-engines is a subject of much importance for agricultural proprietors. They obviate many of the difficulties connected with steam-engines and boilers, such as weight, transport, inconvenience of carrying water and combustible, danger of fire, and constant supervision. These competitive trials were specially designed to test the deficiencies of this class of engine; and it was hoped that a thoroughly serviceable and efficient agricultural oil-motor might be the result. Unfortunately many makers who had hitherto given little attention to the subject were induced, in order to take part in the competition, to construct engines too hastily. Badly designed motors were the natural result, and the same may, in the Author's opinion, be said of the English engines tested at Cambridge in 1894. In the course of the next few years these difficulties will certainly be overcome. The trials at Berlin showed, not the perfections of portable oil-motors, but the defects to be remedied.

Twenty-seven engines were exhibited, viz., six portable and five stationary engines, from 8 to 12 HP.; six portable and ten

stationary engines from 2 to 4 HP.; some were afterwards withdrawn. No maker was allowed to have more than two engines tested. Fifteen firms competed, all German except that of Robey. Drawings with detailed description of all the motors are given in the original Paper. The Author emphasises the fact that the engines, both portable and stationary, were tested solely for their suitability for agricultural purposes.

The following Table gives the names of twenty-five engines, their dimensions, and a summary of some of the results of the trials at full power only, arranged in order of merit:—

Name of Engine.	Type.	Cylinder, Horizontal or Vertical.	Diameter of Cylinder.	Stroke.	Revolutions per Minute.	B.HP.	Consumption of American or Russian Oil per B.HP. per Hour.	Heat Efficiency.[1]
			Inches.	Inches.			Lbs.	Per Cent.
Altmann. .	Portable	Horizontal	9·0	15·7	209	8·16	0·83	15·7
Seck . . .	Stationary	Vertical	7·5	7·5	302	4·23	0·96	14·5
Swiderski .	Portable	,,	6·6	7·0	315	3·96	0·96	13·5
Swiderski .	Stationary	,,	9·8	9·8	249	10·00	0·82	13·2
Schwartzkopff	Portable	Horizontal	9·8	15·7	193	8·88	1·01	12·9
Dürkopp .	Stationary	,,	8·6	13·3	211	8·50	1·00	12·9
Schwartzkopff	,,	,,	6·6	11·8	234	3·66	1·16	12·5
Altmann .	,,	,,	11·0	15·7	209	12·10	0·93	12·4
Langensiepen	Portable	,,	8·6	7·8	304	7·33	1·05	12·4
Seck . . .	,,	Vertical	7·5	7·5	300	4·40	1·02	12·0
Hille . .	,,	Horizontal	7·8	15·7	244	10·56	1·10	11·6
Langensiepen	Stationary	,,	8·6	10·0	271	7·82	1·13	11·5
Grob . . .	Portable	Vertical	7·3	7·3	290	3·88	1·16	11·5
Butzke . .	Stationary	,,	6·7	13·3	275	4·13	1·23	10·4
Grob . . .	Portable	,,	9·0	9·0	252	7·12	1·21	10·3
Deutz . .	Stationary	Horizontal	6·1	9·4	229	4·00	1·26	10·2
König Hütte	,,	,,	9·4	17·7	175	9·80	1·30	10·0
Körting . .	,,	Vertical	6·9	10·8	222	4·15	1·32	9·8
Daimler . .	,,	,,	6·9	11·0	220	3·25	1·33	9·7
Robey . .	,,	Horizontal	6·0	9·0	300	1·82	2·61	5·0
Deutz . .	Portable	Vertical	7·8	9·4	297	9·19	0·96	Not given
Daimler . .	,,	,,	6·8	11·0	221	3·71	1·25	Do.
Dürkopp .	Stationary	Horizontal	6·9	11·0	224	4·46	1·28	Do.
Hille . .	,,	,,	5·1	9·0	250	3·12	0·99	Do.
Januschek .	,,	,,	6·6	13·3	318	2·38	1·47	Do.

All were 4-cycle engines; they varied chiefly in their method of vaporizing the oil, valve-gear, ignition, and regulation of the speed. The vaporization or gasification of the petroleum may take place

[1] Heat efficiency is percentage of heat turned into work to total heat supplied.

in different ways. Sometimes it is sprayed into a red-hot space, called the vaporizer, and converted into vapour by the heat, the piston then drawing it into the cylinder together with a proper quantity of air. Sometimes the petroleum is broken up by a blast of air, and injected into a hot chamber, a certain amount of heat being necessary to prevent the re-condensation of the oil vapour. Some makers use all or part of the gases of combustion to heat the vaporizer. The oil is sometimes vaporized in a separate space, sometimes an air-chamber is used. Although the vaporizer must always be heated, it need not be kept red-hot unless it also serves to ignite the charge. If the heat is not supplied by the gases of combustion a lamp is used, or, the vaporizer being open to the cylinder, the heat of the explosions is sufficient to maintain it at a proper temperature. A lamp must always be used at starting. The vaporizer is the most important part of the engine, because if the oil is imperfectly vaporized the consumption is increased, and dirt accumulates in the engine. The sprayer is usually a kind of nozzle with fine holes, through which the oil is injected into the stream of air. The valve-gear is about the same as in gas-engines. Ignition is generally with a hot tube heated by a lamp. There is no timing valve, the tube being open to the cylinder, but the gases do not ignite until the end of the compression stroke. In some engines the vaporizer is kept red-hot and ignites the charge. Very little air must in this case be used to spray the oil, for if the mixture in the vaporizer were inflammable premature ignition would take place. Until the moment of ignition, therefore, the charge should contain too little air to burn, and air for combustion must be separately admitted, and forced by the compression stroke into the vaporizer. This arrangement, introduced by Grob, is also used in the Daimler.

In reviewing the portable engines the Author remarks that nearly all were ordinary stationary motors mounted on wheels, with the addition of a condenser, an oil and sometimes a water-tank. The judges considered that the aim should be to produce motors complete in themselves, with as little vibration as possible. A decided preference was given to those with horizontal cylinders. With vertical cylinders, the parts of the motor vibrate perpendicularly, and in a portable engine this action, especially on bad soil, causes the wheels to sink into the ground. During the trials the Seck 4-HP. stationary motor consumed 0·96 lb. of petroleum per B.HP. hour; in the portable engine of the same type the consumption increased to 1·48 lb. per B.HP. hour, and the vibrations were very marked. After the engine had been more firmly fixed the consumption fell to one pound.

The trials began by an inspection of all the engines at work, that the smell might be noted. They were then started cold, and observations were made of the time required before they were in full working order, the difficulty of starting, and whether a lamp was sufficient to heat them, without the addition of a fan. A

Prony brake, an indicator, a counter and tachometer were then added. It is of importance to determine the variations in the speed in oil-motors, as they are chiefly governed by cutting out ignitions. In most agricultural engines, even at full power, from 10 to 20 per cent. of the ignitions are missed, on account of the variable nature of the work. During these trials, therefore, the ignitions per minute were counted. Each maker supplied his own lubricating-oil. The consumption of petroleum was carefully noted, but it was not always possible to measure the quantity of cylinder cooling water.

The engines were worked, at the different powers, without stopping to test their smooth and regular running. Note was also taken of their cleanliness. When the oil was not perfectly burnt, the result was not only a larger consumption, but need for frequent cleaning. A point of importance was whether this cleaning could be carried out by an ordinary labourer, but with most of the engines this was not the case. The protection of the different lamps from sudden extinction, particularly when burning in the open air, was also observed, and specially the arrangements for cooling the circulating water. This water on leaving the cylinder jacket is usually cooled by a current of air from a fan, and it is essential that the fan be driven with regularity, and the pulley and strap not allowed to get wet. In many of the motors it was found impossible to work continuously, because the fan strap slipped or came off, and the water was insufficiently cooled. Other difficulties in this respect were also experienced.

After the brake trials, the engines, both stationary and portable, were tested while driving threshing-machines; in this work some of them broke down. The best were then selected for a final trial of sixty consecutive hours. These were the Deutz, Hille, Schwartzkopff, Seck, Dürkopp, Langensiepen, and Körting.

This trial was purposely made as arduous, and the power as intermittent, and as much like agricultural work, as possible. The working efficiency was tested under varying loads, two different oils (Russian and American), and other conditions subject to change during work in the fields. The engines were watched night and day, and the amount of attention they required was noted. The power developed was used to generate electric light, and to drive threshing- and sawing-machines. Although all the motors ran through this trial, some with difficulty, the judges considered that none were worthy of a first prize. With some, when in full work, the water was not properly cooled, the cylinders became too hot, and a violent shock was produced at each explosion. In others the lamp went out, and with all, especially the portable, much vibration was observed, due principally to insufficient cooling of the circulating water. The stationary engines, being connected to a water-main, did not vibrate so much. The farmers complained most of the difficulty of varying the power in the portable motors.

After the trial they were cleaned in the presence of the judges. The small Deutz and Körting were found less dirty than the others, and took only from twenty-five to forty minutes to clean. The larger engines required from forty to seventy minutes, and two or three men were usually employed. Most of them were found in very good condition.

As the heat efficiency could not be determined without knowing the heat value of the combustible, two samples, one of American, one of Russian petroleum, were sent to the Chemical Station, to be tested for heating value and chemical composition, with the following results :—

American petroleum—constituents, C 84·54 per cent.; H 14·08 per cent.; O 1·38 per cent.
Russian petroleum—constituents, C 85·52 per cent.; H 13·98 per cent.; O 0·50 per cent.

American petroleum—heating value per lb., 19,380 T. U.; specific gravity at 15° C., 0·797; flashing-point (Abel), 25° C.
Russian petroleum—heating value per lb., 19,580 T. U.; specific gravity at 15° C., 0·825; flashing-point (Abel), 31·5° C.

The results of the trials at the four powers developed, including time required for heating up, number of ignitions missed, and piston-speed, are given in the original Paper. The weight, price, and size of each engine are also added.

The consumption of petroleum, as shown in the Table, varied greatly, the lowest being in the Altmann, 0·83 lb. per B.HP. hour; the mean consumption of larger power was about 1 lb. per B.HP. hour. The number of ignitions missed show how much the power can be increased; in agriculture, where the amount of work varies greatly, this is of special importance. The Author also calculates the actual power exerted per unit of piston-surface, and unit of time, in other words, the absolute, or what he calls the specific efficiency of the engine. Although the judges did not intend to base their awards upon this specific efficiency, it was found that the engines developing the highest absolute power were always the best in other respects.

When they were run at half instead of full power, the consumption of oil and number of explosions missed increased considerably. In agricultural work the mean power should be between these two. For instance, the 88 HP. Altmann ought normally to develop 6 HP., and its consumption would then be about 1·1 lb. oil per HP. hour. As the consumption of petroleum is relatively very high when the engines are running empty, it is not advisable that they should do so for long. On the other hand, starting, especially for larger powers, is often troublesome. The times required for starting, and the cleaning after a short run, are given in the original Paper.

The indicator diagram is the best guide for studying the cycle of work in a cylinder, especially if a brake experiment be made at

the same time. The soot collecting inside the indicator, especially in oil-engines, may however affect the friction, or an error arise in counting the number of ignitions missed, when not counted continuously. The Author selects one diagram as an example, to explain a method adopted by him to calculate the working, with reference to the distribution of heat. It is mentioned in his Paper on "A Dynamic Theory of Steam-Engines" in the Zeitschrift des Vereines deutscher Ingenieure (1892, page 1). He considers the indicator diagram valuable chiefly to show how work is produced, and how expended. In the usual method of calculating it the total indicated work is shown, but no count is taken of the fact that this is only a fraction of the total work produced by the combustion of the petroleum, and converted into pressure on the piston. In studying an oil-engine it is important to know what becomes of the work, and therefore the indicator diagram must be divided into parts representing so many fractions of work done. The contents of these areas are calculated by the Author in a special way, and he shows the amount of work done during admission, compression, expansion and exhaust, by means of vertical ordinates. Account must always be taken of the pressure of the atmosphere on the outer face of the piston. The actual work done will be the difference between the work of admission, compression, expansion, and exhaust, and that of driving back the air. The latter should be subtracted from the work of expansion to give the true indicated work.

The influence of the compression space is considerable in all 4-cycle engines. The Author shows the proportion between it and the total cylinder volume in all the motors. Thus in the Dentz the compression was nearly half the total volume. During explosion the pressure rose from $7\frac{1}{2}$ to nearly 20 atmospheres. If there were no compression space, the whole of this rise in pressure would be immediately converted into useful work on the piston; with the present methods of construction the greater part is wasted. This pressure generated in the compression space being, like the other values, translated into work and represented by an ordinate, the Author proves that it is equal to about three times as much as the indicated work shown in the diagram. If to it be added the energy of the gases discharged, it will be seen that the work wasted is far greater than the work done. The diagram of this pressure, which is shown as the clearance space at one end of every indicator diagram, ought really to be added to it in estimating the work done by the heat given to an engine.

The Author classifies the work as follows:—

1. Total work, or that shown in all the diagrams combined.
2. Work of explosion, or difference between the absolute and compression work.
3. Work of expansion.
4. Work lost in compression space.
5. Indicated work.

6. Work done on the brake.
7. Work of compression.
8. Work of driving out the air.
9. Work of friction.

All these are represented graphically by curves in the original Paper, and the Author estimates that only about one quarter of the total work is shown on the brake, the rest being absorbed in friction, compression, and the cycle of work. The mean pressures exerted during these different kinds of work, the friction pressure per unit of piston surface, and the maximum pressure of expansion and compression, are all shown in tables, a study of which reveals how the heat developed has been expended, and how much its utilization depends upon the dimensions of the engine, &c. It is not probable, however, that 4-cycle engines can be greatly improved in this respect, because a compression space is indispensable.

Another table gives the proportions in which, in the different engines, the nine kinds of work were distributed. Thus in the Altmann the total work was 70 per cent. of the total heat given. The heat utilization in this motor was therefore good, but unfortunately there was much vibration.

The Author concludes with a comparison of steam, petroleum, and other heat-agents. He is of opinion that a field is open for oil-motors, which are the most convenient for agricultural purposes, and avoid the difficulties of steam- and generator-gas-engines. They are not, however, so simple, and the motive power, explosive gas, has not the same properties as steam; they need frequent cleaning, and much care and attention, but they utilize the heat developed extremely well. In most of the engines there were parts too delicate to be handled by common labourers, although portable motors ought to be made to bear rough treatment, shaking and jolting over bad roads. Although the engines were in some respects defective, many with slight modifications would be suitable for field-work. Time, patience, and attention to detail are needed to attain perfection, and few things can contribute more to this desirable result than careful and accurate tests.

B. D.

Trials of Oil-Engines at Meaux, France. By — RINGELMANN.

(Bulletin du Syndicat Agricole de Meaux, June 15, 1894.[1])

The Author gives the results of competitive trials of oil-engines made by the Société d'Agriculture at Meaux, in May 1894. Eight engines were tested: two English (Hornsby-Akroyd and Griffin), both stationary; three French (a Merlin

[1] Reproduced *in extenso* in the "Bulletin de la Société d'Encouragement pour l'Industrie Nationale," Feb. 1895, p. 83.

portable engine and two Niel, one stationary and one portable); two German Grob motors, one stationary, one portable; and one Swiss stationary, by the Société Suisse de Winterthur. The following Table gives the principal dimensions and results:—

CONDENSED TABLE OF OIL-ENGINE TRIALS.

Name of Engine.	Diameter of Cylinder.	Stroke.	Revolutions per Minute.	Consumption of Russian Oil per B. HP. Hour.	Brake HP. Maximum.	Thermal Efficiency.[1]	Cylinder Cooling Water per Hour.
	Inches.	Inches.		Lbs.		Per cent.	Lbs.
Grob (stationary) . .	$7\frac{2}{5}$	$7\frac{2}{5}$	311	0·59	7·3	21·2 max.	483
Niel „ . .	$7\frac{1}{8}$	$14\frac{1}{8}$	183	0·67	6·2	18·7	341
Merlin (portable) . .	$6\frac{7}{10}$	$6\frac{7}{10}$	283	0·76	4·8	16·6	145
Winterthur (stationary)	$6\frac{3}{10}$	$9\frac{2}{5}$	226	0·84	5·2	14·9	133
Grob (portable) . . .	$7\frac{2}{5}$	$7\frac{2}{5}$	263	0·92	6·2	13·7	2,557
Griffin (stationary) . .	6	12	218	0·93	7·4	13·6	330
Hornsby-Akroyd (stationary)	8	$14\frac{7}{10}$	205	1·0	5·7	10·4	649
Niel (portable) . . .	$7\frac{1}{8}$	$14\frac{1}{8}$	177	1·54	6·4	8·2 min.	4,752

The Author first draws attention to the fact that oil-engines are much more generally used in Germany and England than in France and America, and very few new types are made in the two latter countries. At the Chicago Exhibition scarcely any American oil-motors were shown. In France the heavy duty on petroleum has hitherto prevented its general use. Till 1893 the duty in Paris was equal to the value of the oil, and though it has since been reduced, petroleum is still six times dearer in Paris than in America.

All the engines were tested with the same Russian oil, supplied by the Society. Its mean density was 0·823 flashing-point (Abel's test), 84° F.; heating value in a Mahler calorimeter 19,872 T.U. per lb.; chemical composition—C 84 per cent.; H 15 per cent.; O and N (by difference) 1 per cent.

Each engine was tested four times, viz.: first running light, then at 2 brake HP., at 4 brake HP., and at maximum load. The experiments were in most cases continued for three or four hours, and the engine was run for about an hour before beginning the trials. Each exhibitor was allowed as much oil as he required, and every precaution was taken to make the trials as complete as possible. The following data were noted: oil or spirit required

[1] Thermal efficiency is the percentage of heat turned into brake-power of total heat of oil.

for ignition and lubrication, consumption of petroleum, barometric pressure, temperature of the air, of the water in and out of the cooling jackets, and of the exhaust gases; quantity of cooling water, number of explosions and of revolutions per minute, and variations in the speed. Indicator diagrams were taken where possible. The brake HP. was determined by a special automatic brake of thin sheet iron, fully described with drawings in the original Paper. All the engines tested were single cylinder, four-cycle and single-acting.

The petroleum was fed into the cylinders either by gravity from a reservoir above, by an oil-pump, or injected with compressed air—a method followed in the Griffin engine, and which certainly contributed to its high thermal efficiency. The engines were started by hand, and all had cooling-water jackets. The cooling of the cylinders should be carefully regulated, for if too much heat is carried off the oil is not properly vaporised; if too little, dissociation and "cracking" may occur, with griping of the piston. The Author is of opinion that the quantity of circulating water ought to be regulated by the number of explosions per minute—in other words by the amount of heat generated in the cylinder. In the Grob and Niel engines the same quantity of water was sent by the pump to the jackets, whatever the power developed. Hence the cylinders in some cases were too much cooled, the loss of heat was great, and the consumption of petroleum excessive, the oil going to heat the cylinder walls instead of being turned into useful work. Thus the water cost too much, not only for the unnecessary work of the pump, but to keep the walls at the required temperature. The best engine in this respect was the portable Merlin, in which the water was sent into the jackets by a pump acting only at each explosion, and checked by the governor whenever the normal speed was exceeded.

Drawings with detailed description and a careful criticism of the engines are given in the original Paper. As shown by the Table the consumption of the Niel portable engine was very large, more than double that of the stationary engine by the same maker, and the thermal efficiency proportionally small; this is attributed by the Author to the large quantity of water circulating in the jacket. The different engines are then reviewed with reference to their thermal efficiency, quantity of heat carried off by the cooling water, heat balance, air used in each engine for the combustion of 1 lb. oil, variations in the speed, and consumption of petroleum. The results obtained under these heads are tabulated, and most of them are represented graphically.

The calorific value of the petroleum, the consumption per hour, and the work done being known, the thermal efficiency can be calculated. Heat is lost to the walls, to the exhaust, by radiation, absorbed by the lamp and by friction. To determine the thermal efficiency the brake HP. developed was converted into calories and divided by the heat units in the petroleum, giving the

proportion of heat turned into work to the total heat supplied to the engine. The best engine in this respect was the Grob stationary; but according to the Author the efficiency of all the oil-engines was much higher than in agricultural steam-engines of the same power. The thermal efficiency is of great importance, for if it is high the engine, although faulty in other respects, can without difficulty be improved in detail.

To ascertain the air used for combustion it was necessary to know the number of explosions per hour, volume of the piston and consumption of oil, and from these the volume of air per lb. oil burnt was calculated. The difference between this actual quantity and the theoretical helped to explain why some engines consumed more oil than others. Either the amount of air admitted was too large, and the charge in consequence not sufficiently inflammable, or the quantity was too small, and incomplete combustion and smoke were the result. The comparison of these figures with the thermal efficiency shows how much air ought in practice to be admitted into an engine cylinder per lb. of oil.

A constant speed is most important, especially in engines intended to drive dynamos. The Griffin and Merlin engines were the best in this respect. The consumption of petroleum per hour increased in all the engines with the power, but not to the same extent; it was much affected by the temperature of the walls and the quantity of air admitted for combustion. The oil required for starting, when running empty, for the lamp, and per day, were also determined. The Author tested these 4 HP. engines during a working day of ten hours, running one hour empty, two hours at 2 brake HP., six hours at 4 brake HP., and one hour at 5 brake HP.

A number of comparative experiments and scientific determinations were also made. Professor Witz has shown that the thermal efficiency increases with the speed of the engine, and that the combustion of explosive mixtures is the more rapid the greater the speed. Dr. Slaby has also demonstrated that the losses of heat to the walls unquestionably diminish with the increased speed. In an experimental engine they fell from 40 per cent. to 33 per cent., when the speed rose from 104 to 170 revolutions per minute. Under this head the Author remarks that in engines giving the highest thermal efficiency when running at 4 brake HP. this efficiency increased with the speed. Thus in the Grob stationary engine the thermal efficiency was 17 per cent. with 312 revolutions, in the Niel it was 15 per cent. with 184 revolutions. He considers that the thermal efficiency rises with the speed of the engine, owing to the better utilisation of the combustible and the smaller loss of heat to the walls. Hence the speed of a gas- or oil-engine is of much importance. If a small power single cylinder oil-motor runs, like a steam-engine, at 100 to 120 revolutions per minute, it is costly, bulky, and the combustible is imperfectly utilised.

The Author proceeds to classify the engines according to their

cost of working, excellence of construction and running, and thermal efficiency. The comparative perfection of their construction was determined according to the balance of the different parts, capacity of the engine for running empty or at any power, regularity of speed, ease in starting, and time required to start. These were calculated according to different co-efficients, and combined in a Table with the thermal efficiency. The Grob stationary engine, although giving the greatest thermal efficiency, was not so good in other respects as the Merlin, and the portable Grob motor was the worst.

The main object of the experiments was to bring these interesting and practical oil motors before the public and make them better known, and the Author hopes that the results published will help to advance the cause and improve the construction, their value for agricultural and other purposes being now generally recognised.

B. D.

On the Resistance of Rivets. By — DUPUY.

(Annales des Ponts et Chaussées, January, 1895, p. 5.)

The Author was entrusted by the Ministry of Public Works (France) with the duty of making a special inquiry into the causes of deterioration of metallic structures, and the subject of the present Paper was the one to which his investigations were first directed.

A great number of experiments were made, both on rivets and on bars, from which a representative selection is given in the Paper, the instruments and methods being fully described and illustrated. A series of nineteen conclusions founded on these experiments is given, eleven of which relate to the behaviour of bars under tensile test, and agree with the conclusions of other experimenters on the same subject. Those relating to rivets are as follows :—

12. Rivets are bars submitted to tensional stress exceeding the original limit of elasticity. The outside fibres appear to be more strained than those near the centre of the rivet.

13. The rivets do not exactly fill the holes but they clamp the plates together with a pressure that gives rise to a resistance to sliding equivalent to a weld.

14. The resistance of the plates to sliding is greater as the limit of elasticity of the material of the rivets is higher.

15. The limit of resistance to sliding is very variable, the causes being numerous and depending on the nature of the material of the rivets, on the temperatures at which the riveting is commenced and finished, and on the method of riveting employed.

16. The resistances to sliding that may in practice be reckoned

on, with a joint consisting of not less than three rivets, are the following:—

Limit of Elasticity of Metal forming the Rivet per Square Inch.	Method of Riveting.	Temperature at which the Rivet is Closed.	Resistance per Square Inch of Sections of Rivet to be Sheared.
Tons.			Tons.
11·4 (iron) . . .	Hand	Bright red heat . . .	2·5
14·0 „ . . .	„	„ „ „ . . .	3·0
11·4 „ . . .	Hydraulic	White heat	3·2
14·0 „ . . .	„	„ „	3·7
14·0 (steel) . .	Hand	Bright red heat . .	2·85
14·6 „ . . .	„	„ „ „ . . .	3·2
14·0 „ . .	Hydraulic	White heat	3·8
14·6 „ . . .	„	„ „	4·2

The hydraulic press used gave a pressure of 38 tons per square inch of rivet-section. In all cases the pressure was maintained till the rivet had cooled to blackness. The riveting cups left no mark on the plates. The material was such as to give an extension of 12 per cent. for iron and 18 per cent. for steel before fracture.

17. This paragraph describes with diagrams the successive steps in the failure of a riveted joint. When there are several rivets to a joint they all yield at once.

18. If yielding has occurred at a joint with deformation of the rivets, the deformation is permanent, but apparently no new effort, which does not exceeed that which caused the partial failure, gives rise to further deformation.

19. The effort necessary to shear rivets, per square inch of the sections to be sheared, is not less than three-fourths of the tensile strength of the rivet per square inch. Having shown that these conclusions are borne out by his experiments, the Author proceeds to discuss various details of the design of iron bridges, as affected by the conclusions, and submits eleven practical rules, among which the following are the most important:—

1. The calculation of riveting cannot be based upon the permissible stress in the bars, the coefficients of safety relating to the rivets not depending in any way on those adopted for the bars.

2. To reduce the stress on the rivets it is desirable not to space the cross-girders at too great distances apart, 13 feet being suggested as a maximum. (This recommendation is founded on a consideration of the longitudinal stresses induced in the rail-bearing girders by the deflection of the bridge, independently of those directly caused by the load. The rail-bearers must share in the extension of the lower boom, and thus strain their attachments to the cross-girders, at the same time exerting considerable transverse efforts on the cross-girders near the ends of the span. (The cross-girders are supposed to be at the level of the lower boom.)

4. In girders with a single diagonal in each panel the secondary

stresses are of considerable importance, and this type of bridge appears best suited to spans not exceeding 25 metres (82 feet).

8. In girders whose booms have a single web, and in those not horizontally braced above and below, vertical stiffeners are desirable.

9. When the secondary stresses are calculated and allowed for, the permissible stresses in tension may be higher than when such a calculation is not made, but this does not apply to the riveting. If the secondary stress on the rivets is not calculated and allowed for, the rivets may be expected to yield, an effect which does not imperil the safety of the structure, but contributes to shorten its life by facilitating the deterioration of the rivets.

10. In bridges of several spans continuous girders are to be preferred when there is no danger of settlement. With continuous girders the length of each boom from pier to pier does not appreciably change, and the riveting of the cross-girders and rail-bearers is therefore less strained by the deformation of the bridge. The maximum section of the booms is also less, which facilitates good riveting. The continuity should not extend over too many spans, as otherwise the efforts necessary to produce the movements resulting from changes of temperature become excessive.

The rules omitted in the summary above are already generally recognised by bridge designers.

In regard to the secondary stresses referred to in rules 4 and 9, calculations are given for certain cases and compared with the observations of Mr. Lethier on the bridge over the Loire at Cosne. The Author controverts the opinion often expressed, that if each panel of a girder has one or more diagonals in both directions the work may be unequally divided between the two sets. The bending moments due to a rigid attachment of cross-girders to booms are also calculated.

C. F. F.

Pump with Constant Discharge.

By GÉRARD LAVERGNE.

(Le Génie Civil, vol. xxvi. 1895, p. 401.)

There are considerable advantages to be gained by making the discharge of a reciprocating pump more uniform. A higher speed and a smaller pump and prime motor, in consequence, can be used; the transmission of power from the motor to the pump becomes simplified with the greater speed of the pump; the suction and discharge pipes can often be reduced in size.

The present article describes a double acting piston-pump in which the discharge is made approximately constant throughout the stroke by a simple arrangement of the valves of the two pump cylinders.

The cylinders are exactly alike and side by side, being cast in

one piece. The pistons are driven from a common shaft with cranks at 120° apart. The cylinders are double-acting. One cylinder draws water from the suction pipe, which has a branch to each end of the cylinder, and discharges into the second cylinder, there being direct communication between the cylinders at both ends. The second cylinder, drawing water from the first, pumps it into the discharge pipe. All the six valves necessary for these operations open towards the discharge. If a complete stroke be divided into twelve equal parts, the delivery in each of these periods is the same; the delivery at each end of the pump separately varies from a maximum to nothing, but the joint delivery of the two ends is nearly constant. This is shown by diagrams of the flow at each end of the cylinders throughout the stroke. The delivery of the pump for one complete revolution is three times the capacity of one of the cylinders. Illustrations are given of pumps of this type as made for various services, and the results are given of tests made with a small pump worked by hand and also driven mechanically at speeds up to one hundred and twenty strokes per minute.

C. F. F.

Contract-Trial of the U.S. Cruiser "Maine."

By Chief-Engineer A. W. Morley, U.S. Navy.

(Journal of the American Society of Naval Engineers, February, 1895, p. 1.)

The "Maine," a twin-screw armoured cruiser of 6,650 tons displacement, was built at the Navy Yard, New York. In arrangement of battery she resembles the Brazilian ship "Riachuelo," but she is larger and has thicker armour and heavier guns. The machinery was constructed by N. F. Palmer & Co., of New York City, the contract price being £147,000. The hull is built of mild steel. The outside keel-plate is $\frac{6}{8}$ inch, the inner plate $\frac{1}{2}$ inch, and the vertical keel $\frac{1}{2}$ inch thick. The outer bottom plating is $\frac{1}{2}$ inch with a double sheer strake, the plating of the inner bottom being $\frac{5}{16}$ inch thick. The frames are spaced 4 feet apart throughout the length of the double bottom and 3 feet at the ends. The bunker capacity is 825 tons.

The dimensions are as follows:—

	Feet	Ins.
Length between perpendiculars . . .	310	0
Length over all	324	4
Beam, extreme, at L.W.L.	57	0
Draught, mean	21	6
Displacement at this draught	6,650	0
Coefficient of fineness	0·596	
„ „ midship section . . .	0·878	

For a length of 180 feet amidships there is a water-line belt of Harveyized steel armour extending from 3 feet above to 4 feet below the water-line, 1 foot in thickness from the top to 1 foot

below the water-line, whence it tapers to 7 inches at the bottom. At the forward end of the armour belt there is a 6-inch athwartship bulkhead. The protective deck, constructed of two layers of 1 inch each, extends from the armoured bulkhead to the after end of the belt, and from there it slopes below the water-line with a thickness of 3 inches. The conning tower is protected with 10-inch armour. There are two revolving turrets, each carrying two 10-inch guns. These guns can fire from right ahead to an angle of 180° on one side and to an angle of 64° on the opposite side. The turrets are of 8-inch Harveyized steel. The unarmoured lower parts of the turrets and the spaces for working and loading the guns are protected by a fixed barbette of 12-inch mild steel. Turrets and guns are worked by hydraulic gear. Besides the heavy guns there are six 6-inch breech-loading guns, seven 6-pounder quick-firers, eight 1-pounders, and four Gatlings. There are four torpedo discharging-tubes.

The engines are of the three-stage compound type. The low-pressure cylinders are placed forward and can be disconnected when working at low powers. All the cylinders are completely steam-jacketed. The valves are of the piston type, made of composition, and are all of the same size. There is one on each high-pressure cylinder, two on each intermediate-, and three on each low-pressure cylinder. The HP.-valves are fitted with balancing pistons working in cylinders cast on the covers of the valve-chests. Live steam is admitted to the under side of the piston, and the upper side is connected with the intermediate receiver. The design of the engine is described in great detail, all dimensions and ratios being given.

The framing consists of hollow wrought-steel columns with the exception of a single ⅄ frame supporting the intermediate cylinder. The diameters of the cylinders are 35·5 inches, 57 inches, and 88 inches respectively, and the stroke is 36 inches.

The propellers are four-bladed, of uniform pitch, and made of manganese bronze. They are 14 feet 6½ inches in diameter, and have a pitch of 16·1 feet. The developed surface is 65·5 square feet, and the projected surface 54·8 feet. The tops of the blades are 6 feet 2 inches below the surface.

There are eight boilers of marine type designed to work at 135 lbs. pressure. The total heating-surface is 19,015 square feet, and the grate-surface 574 square feet. An undergrate draught is supplied by sixteen Sturtevant blowers running at 545 revolutions. The fan-engines have two cylinders, 6 inches diameter and 5 inches stroke, and drive fans 56 inches diameter and 30 inches wide. Each fan can supply 25,000 cubic feet of air per minute.

The weight of propelling-machinery, including engines, boilers, and mountings, fittings in engine- and boiler-rooms, funnels, ventilators, distilling-apparatus, tools, heating-apparatus, and water in boilers, condensers and pumps, but not including stores, spare gear, capstans, windlass, turret-turning engines, steering-engines, or winches, is 892 tons.

The official trial took place on the 17th of October, 1894. It consisted of a run of four hours' duration. The speed was estimated at 17½ knots, the displacement on trial being 5,500 tons. The total I.HP. was 9,293, and the revolutions per minute 124. There were 2·05 square feet of heating-surface for each HP. developed, and 16·2 I.HP. per foot of grate. The I.HP. per ton weight of propelling-machinery was 14·2. The coal burned per foot of grate per hour was 35·3 lbs., and the coal per I.HP. per hour 2·18 lbs.

S. W. B.

Notes on the Accident to the Mail Steamer "Gascogne."

By J. GAUDRY.

(Mémoires et Compte rendu de la Société des Ingénieurs de France, April, 1895, p. 570.)

The "Gascogne" was built by the Compagnie des Forges et Chantiers in 1886, and was 525 feet long, and of 7,890 HP. During her reconstruction last year not only were her four masts replaced by two, but her engines were altered from compound to quadruple-expansion, while new boilers were put in. The old engines were tandem compound, three pairs of cylinders—the high pressure over the low-pressure—driving three cranks at angles of 120°. These engines were retained, the steam connections being altered as follows: The forward small cylinder was made the high-pressure cylinder, and from this the steam passed to the other two small cylinders. From these it was again expanded into the centre large cylinder, and thence again into the two other large cylinders. The boiler-pressure was increased with the new boilers from 85 lbs. to 156 lbs.

With these alterations the "Gascogne" made a successful voyage to America and back; but on the third day of her next trip, while running at 62 revolutions and 17⅔ knots, the cast-iron piston of the centre large cylinder broke across. To enable the engines to proceed, the pistons and connecting-rod were removed from the centre tandem engine, the steam distribution being altered as follows: (i) the forward small cylinder; (ii) aft small cylinder, omitting the centre small cylinder, and thus giving no expansion; (iii) the centre lower cylinder, which, having no piston, became only an intermediate receiver; (iv) the forward and aft large cylinders.

After seventeen hours spent making this alteration the engines were started again at 40 revolutions and 11 knots. The strains on the shaft, however, were very unequal, and heavy weather coming on, the bearings and brasses heated and seized, the brasses of the aft connecting-rod having to be renewed. This caused another stoppage, and the speed was again reduced to thirty revolutions and 8 knots, and with a few more stoppages for heated bearings the vessel reached New York.

From this experience the Author concludes that the "Gascogne" is a satisfactory type of vessel, and regrets that, in view of the great difficulty of effecting any repairs at sea, the space round engines and boilers on most ships is so confined. He is of opinion that a steam-pressure of 156 lbs. per square inch is sufficient, as even with this, trouble is experienced in working the boilers satisfactorily. He suggests that part of the 20 per cent. saving in coal consumption, since the conversion of the "Gascogne" to quadruple-expansion, is due to this high boiler pressure. He remarks that the unequal strains arising when, owing to any breakdown, a portion of a triple- or quadruple-expansion engine is disconnected, are much intensified when the cranks are a great distance apart, and thinks that future progress should be in the direction of independent units, capable of isolation. He also advocates the absence of masts, except for signalling, in vessels of this class.

R. B. M.

The Mineral Resources of Siberia. By A. FONIAKOFF.

(Revue Universelle des Mines, February, 1895, p. 109.)

This memoir is the second of a series,[1] and gives a detailed description of the occurrence in Siberia of some of the principal metallic ores.

Silver and lead are worked chiefly in the Altai district on the Mongolian frontier, to the south of Tomsk. There exist evidences of very ancient workings during the Bronze Age. The famous argentiferous-galena mine of Zmeinogorsk constituted for upwards of a century the chief source of silver for the Russian mint, but has since been abandoned. The maximum depth of this mine was nearly 900 feet. The ore contained from 1·83 oz. to 93 ozs. of silver per ton, and from 15 per cent. to 30 per cent. of lead. The chief mine now being worked is at Zirianovsk, giving an output of 8000 tons of ore per annum, of a richness of 14 ozs. to 28 ozs. of silver per ton. This ore is conveyed no less than 220 miles to the nearest smelting works. The silver-mining industry of Altai has declined to a marked extent since 1868, owing to the abolition of serfdom in 1861, and increased foreign competition. A table of the annual production of silver and lead from 1859 to 1891 shows that whereas 17½ tons of silver and 668 tons of lead were produced in 1859, these figures fell in 1891 to 9½ tons and 180 tons respectively. Silver is also mined and smelted in the Kirghis Steppes, of which Karkaralinsk is the chief town. The production of this district in 1887 was 3 tons of silver and 183 tons of lead. In the Nertchinsk district to the east of Lake Baikal, the once flourishing silver mining industry has all but died out. Silver is also known

[1] Revue Universelle des Mines, vol. xxiii., third series, p. 117.

to occur, and is to a trifling extent worked, near Minussinsk, near Yakutsk, and in the extreme east. A table is given showing the production of each district of Siberia between 1880 and 1887. The total annual output has increased from 10 tons at the former date to 13½ tons at the latter.

Copper is abundant in Siberia, but is worked only in the Kirghis Steppes, and in the Altai region. This industry has declined rapidly since 1880. Rich deposits of copper ore, which, however, are not mined, exist near Krasnoiarsk, Nertchinsk, and in the east opposite the island of Saghalien.

Antimony.—The only rich deposit of antimony in Siberia is near Mount Bogutchan, on the River Amur. It consists of a bed of stibnite about 13 inches thick, but is not mined.

Mercury is obtained only in one district, near Yakutsk. It is also known to exist near Nertchinsk, and on the River Amur, and could probably be profitably mined in the latter district for use in the extraction of gold from its ores by the amalgamation process.

Tin occurs in abundance in the Trans-Baikal district, but all workings have been abandoned since 1843.

Sulphur is produced only in the Altai region, the annual output being 3,200 tons, obtained from pyrites. Native sulphur also occurs near Nertchinsk, but is not mined.

Salt is obtained chiefly from the salt lakes which abound in Siberia. In the Kirghis Steppes is situated Lake Kariakovskoë, from which 16,000 tons per annum of excellent salt are derived. In the Altai district is a group of 40 lakes, of which the annual pruduction of salt is from 30,000 to 40,000 tons per annum. In the Krasnoiarsk and Irkutsk regions, salt is obtained from subterranean salt beds by brine wells. Near Yakutsk are several remarkable deposits of rock-salt, too far from populated regions to be profitably worked.

Ornamental stones comprise porphyry, marble, lapis lazuli, and nephritis, a variety of tremolite, greatly prized in India and China as a charm.

Fireclay is found near Irkutsk, Krasnoiarsk, and in the Kirghis Steppes.

A. P. H.

Experiments on Mine Ventilation.[1] By R. Hausse.

(Der Civilingenieur, 1895, p. 19.)

The Author continues the memoir from a former number of the Civilingenieur, as follows:

(4) *Ventilator resistance; reduction of pressures to a standard rim-velocity.*—By "ventilator resistance" is understood that resistance which is offered by the ventilator to the passage of a current of air.

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[1] Minutes of Proceedings Inst. C.E., vol. cxx. p. 427.

On account of this resistance two differently constructed or unequal ventilators require different rim-velocities to produce the same depression. Since the rim-velocity is proportional to the volume of air and to the square root of the depression, depressions can be reduced to a standard rim-velocity. Murgue uses the term manometric deficiency to denote the ratio of the initial depression to the theoretical depression due to the rim-velocity $\left(\frac{u^2}{g}\right)$. In judging the performances of ventilators by their manometric efficiencies, it is to be remembered that the usual assumption, that "the same depression gives the same quantity of air per unit of time through a given mine whatever be the ventilator used," is not correct.

(5) *General determination of the performances of ventilators.*—The mechanical efficiency of a ventilator is the ratio of the power L_u, actually spent in delivering the quantity of air Q at a total depression h_i, to the indicated HP. L_i of the steam engine, or to the break HP. L_b transmitted to the ventilator shaft.

$$\eta = \frac{L_u}{L_i}$$

$$\eta_1 = \frac{L_u}{L_b}.$$

The mechanical efficiency is the most important measure of the performance of a ventilator, but is not, without modifications, suitable for comparisons of different ventilators. The relations of the mine resistance and the type of ventilator to the quantities Q and h have to be investigated; the experiments necessary are divided into four classes.

Experiments with constant resistance and similar types of ventilators.—From these the important law, "The number of revolutions u_1 and u_2 are directly proportional to the air volumes Q_1 and Q_2 and to the square roots of the corresponding depressions h_i and h_{i1}," is obtained. From this four important deductions can be drawn: (1) The air-volumes and depressions measured at different velocities can be reduced to a standard velocity, and can therefore be made directly comparable. (2) $\frac{Q^2}{h}$ is independent of the rim-velocity of the ventilator. (3) If Q and h are known for one velocity of the ventilator they can be calculated for any other velocity. (4) The power of a ventilator is proportional to the cube of its velocity.

Experiments with varying resistances and similar ventilators.—Various experiments on this point are discussed, and it is concluded that the principle that "no shaft can be made too large" is correct as regards ventilation.

Experiments with constant resistance but different types of ventilators.—These experiments are intended to throw light on the performances of ventilators as regards volume of air delivered,

depression and useful work. The volume of air actually delivered may be compared with the volume got by taking the product of the rim-velocity and the area of the cylindrical section at the rim. For the Guibal ventilator at the Döhlen shaft this comparison gives 1·2 per cent. of the theoretical volume, for the Winter ventilator at the Albert shaft 19·7 per cent., for the Winter ventilator at the Oppel shaft 7·3 per cent. More important is the comparison of the depressions produced at a standard rim-velocity, 20 metres per second. For the Mehner shaft Guibal ventilator, Albert shaft Winter ventilator, and Oppel shaft Winter ventilator, the ratios of the effective to the theoretical depressions are 0·75, 0·54, and 0·27 respectively.

In section (3) it was shown that the Guibal ventilator was more effective than the Albert shaft Winter ventilator as regards the depression produced, but less effective as regards the quantity of air delivered at equal depressions. The Author thinks that in future it will have to be considered whether cheap open ventilators may not in many cases be more advantageously used than the comparatively expensive Guibal ventilators.

Experiments with varying resistances and different types of ventilators give only the relation of the sum of the mine and ventilator resistances to the corresponding depression and volume of air delivered. Experiments on different mines are therefore not directly comparable.

(6) *Determination of pressure and of velocity of air. Pressure of an air-current and its measurement.*—Let p be the aerostatic head, p_1 the aerodynamic head, and v the velocity of the current; then

$$p = p_1 + \frac{v^2}{2g}.$$

With a blower ventilator let h_p be the aerostatic pressure, h_{ps} the aerodynamic pressure, h_{pt} the total pressure, and h_{pm} the manometer pressure. In an exhauster ventilator, let h_d be the aerostatic depression, h_{da} the aerodynamic depression, h_{dt} the total depression, and h_{dm} the manometer depression, and let b be the barometer depression of the external atmosphere. Then

$$h_p = p - b,\ h_{ps} = p_1 - b = p - \frac{v^2}{2g} - b \quad . \quad (11)$$

from which

$$h_p = h_{ps} + \frac{v^2}{2g} \quad . \quad . \quad . \quad . \quad . \quad (12)$$

Again

$$h_d = b - p \quad . \quad . \quad . \quad . \quad . \quad (13)$$

and it can be shown in the same way that—

$$h_d = h_{da} - \frac{v^2}{2g} \quad . \quad . \quad . \quad . \quad . \quad (14)$$

It is easy to show that

$$h_{pt} = h_{ps} + \frac{v^2}{2g} \quad . \quad . \quad . \quad . \quad . \quad (15)$$

The corresponding relation for exhaust ventilation is not so evident, but it can be shown that—

$$h_{dt} = h_{da} \quad . \quad . \quad . \quad . \quad . \quad (16)$$

If the resistance pressure be denoted by h, then—

$$h = h_{pt} - \frac{v^2}{2g} = h_{pa} \quad . \quad . \quad . \quad . \quad (17)$$

and

$$h = h_{dt} = h_{da} - \frac{v^2}{2g} \quad . \quad . \quad . \quad . \quad (18)$$

Since in mine-ventilation it is usually the pressure of air which has to be measured, the manometer pressure h_{pm} and the manometer depression h_{dm} will be identical with the aerodynamic pressure and depression respectively; therefore from (12) it can be shown that

$$h_{pm} = h_p - \frac{v^2}{2g} = h_{pt} - \frac{v^2}{2g} \quad . \quad . \quad . \quad (19)$$

In the same way

$$h_{dm} = h_{dt} \quad . \quad . \quad . \quad . \quad . \quad (20)$$

Experiments were made to determine the manometer pressure, a horizontal shaft 138·6 metres long and 0·07 square metre in section being used. The required pressure and velocity of the air were produced by blowing in compressed air. The arrangement of the apparatus is described in detail. Different forms of mouth were given to the manometer tube. A manometer tube with curved mouthpiece gives the exact depression when the mouth is directed against the current, but gives the pressure $+ 1{\cdot}79 \frac{v^2}{2g}$ when the mouth is directed with the current. The results from a straight tube are also discussed, and it is deduced that the form of the end of the tube has a great influence on the results.

Determination of the velocity of an air-current.—The Author discusses the calibration of anemometers by (*a*) observations on a current of known velocity, (*b*) moving the anemometer in a straight line through air at rest, (*c*) moving the anemometer in a circle through air at rest; and he shows that the results are different in the three cases. In order to attain accurate results with any anemometer, the method of its calibration should therefore be known. He describes two new anemometers for the measurement of small velocities; one being formed by a pendulum, consisting of a collodion balloon and a silk thread, which is placed in the current to be measured; the other is a multiplication anemometer, in which the air impinges on an elastic membrane sensitive enough to be perceptibly deflected with very small velocities of air. This membrane is connected to a manometer, from which the deflection, and therefore the velocity of air, is measured.

The Paper is accompanied by a sheet of drawings illustrating the apparatus used. A. S.

Influence of Heat on the Tenacity of Manganese Bronze.

By M. RUDELOFF.

(Mittheilungen aus den königlichen technischen Versuchsanstalten zu Berlin, 1895, p. 29.)

In a former Paper[1] the Author gave the results of experiments on some metals at varying temperatures up to 400° C. The fact there shown, that the strength of manganese bronze is approximately independent of the temperature within these limits, occasioned Mr. C. Heusler of Bonn to undertake similar experiments with bronzes having different proportions of manganese; the results of which are given in the present Paper. Three different kinds of bronze were tested; the proportions of manganese being 5·37, 7·3, and 9·4 per cent. The specimens were cast at the Isabellan works, Dillenberg. The shape of the test-specimens and the manner of carrying out the experiments were in general the same as in the former experiments. The relation of stress and strain of each specimen is given by a curve; these curves, for each proportion of manganese, being collected in a single diagram. A corresponding diagram, showing the variation of elastic limit, yield-point, breaking strength and expansion with temperature, is given for each bronze. Three diagrams, showing the variation of the yield-point, the breaking strength and extension, with varying proportions of manganese, are given, the manganese varying from 3 to 14 per cent. The principal conclusions drawn from these experiments are that (*a*) a bronze with 5 to 6 per cent. of manganese is most useful for machine parts in which tenacity is of importance, (*b*) the addition of manganese to copper varies the properties of the mixture in much the same way that Mr. Hadfield has shown to be the case for steel; namely, the tenacity of the bronze increases with the percentage of manganese up to a certain limit, then decreases, and with a still further increase of manganese the strength of the bronze again increases.

A. S.

On Boron Steel. By H. MOISSAN and G. CHARPY.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxx., 1895, p. 130.)

A mixture of amorphous boron and reduced iron was heated in a tube traversed by a current of hydrogen. The resulting compound, which contained about 10 per cent. of boron in the form of iron boride, was then added to a suitable quantity of mild steel in a state of fusion. After melting a second time an ingot

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[1] Minutes of Proceedings Inst. C.E., vol. cxvii., p. 461.

was obtained weighing rather more than 2 kilograms, and having the following composition [1]:—

Boron	0·58
Carbon	0·17
Maganese	0·30
Silicon, phosphorus, sulphur	traces

The metal can be forged easily at a dull red, but crumbles under the hammer if too strongly heated. On testing it by the method of cooling, the temperature curve showed a well marked evolution of heat at 1,140° C. Other critical points were detected at 1,040°, 830°, 730°, and 660°. The last three correspond to the three critical temperatures, a_1, a_2, and a_3, of mild steel, but they are somewhat lower and not so well defined.

The phenomenon observed at 1,140° C. resembles the recalescence of hard steel. It is met with in alloys containing as much as 10 per cent. of boron. The critical point at 670° C., in the case of ordinary cast metal, disappears altogether after fusion with boron, and is replaced by that at 1,140°.

Mechanical Tests.—The following Table gives the result of experiments on bars of boron steel, 4 millimetres × 2 millimetres × 90 millimetres. In some cases the metal was annealed, and in others it was quenched in water after heating to a given temperature. Control experiments were made with carbon steel treated similarly.

—	Boron Steel.		Steel with 0·07 of Carbon.		Steel with 0·37 of Carbon.	
	Breaking Strain.	Elongation per cent.	Breaking Strain.	Elongation per cent.	Breaking Strain.	Elongation per cent.
	Kilos.		Kilos.		Kilos.	
Annealed	46·0	11·0	33·4	22·7	55·3	16·1
Tempered at 800° C.	85·6	5·1	34·8	15·2	92·4	2·7
„ 900° C.	120·0	2·7	42·5	13·5	117·4	1·7
„ 1,100° C.	129·5	3·1				
„ 1,200° C.	92·3	0·9				

It appears, therefore, that boron renders iron capable of being tempered, in the sense that it becomes capable of bearing a greater load, and that the elongation before rupture is diminished. But it does not resemble ordinary steel in hardness, since the tempered pieces could be filed as easily as those which had been annealed.

G. J. B.

[1] Evidently percentage composition is meant.—G. J. B.

On the Electrostatic Capacity of Coils. By J. Cauro.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxx., 1895, p. 308.)

It was discovered by Hopkinson that the mode of winding coils usually employed to prevent self-induction causes them to have an electrostatic capacity which may for some purposes be objectionable. Chaperon discovered a means by which this difficulty might be partially removed, and the Author has succeeded in still farther reducing it, by winding in alternate layers, starting always from the same end and returning to it in a line parallel with the axis. Details are given of the apparatus used in the experiments, and of the results obtained with coils wound in the ordinary way, and on Chaperon's system, and on the plan now proposed by the Author, from which the advantages of the new method are evident.

G. J. B.

Influence of Low Temperatures on the Attractive Power of Permanent Magnets. By Raoul Pictet.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxx., 1895, p. 263.)

A compound horse-shoe magnet, weighing 493·5 grams, capable of sustaining a weight of 3,226·5 grams, was immersed in a bath of alcohol, which could be artificially cooled.

The magnet was fixed vertically with the poles upwards, and supported a glass plate 3 millimetres thick. The armature, which rested on the glass, was suspended from the pan of a delicate balance, and an electric circuit was arranged so as to indicate its slightest upward movement.

In the following Table the strength of the magnetic attraction in grams is given for every tenth degree :—

Temperature.	Magnetic Attraction.	Temperature.	Magnetic Attraction.
° C.	Grams.	° C.	Grams.
+ 30	57·31	− 40	66·70
+ 20	58·48	− 50	68·15
+ 10	59·81	− 60	69·64
0	61·04	− 70	71·12
− 10	62·42	− 80	72·70
− 20	63·93	− 90	74·18
− 30	65·35	−100	75·80

G. J. B.

An extremely Sensitive Galvanometer. By Pierre Weiss.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxx., 1895, p. 728.)

In place of the ordinary astatic system, the Author uses vertical needles in pairs, the north pole of the one being opposite to the south pole of the other, the distance between the needles being very small in comparison to their length.

He claims the following advantages for this arrangement. The magnetic circuit being almost closed, the intensity of magnetisation remains constant for a long time. The moment of inertia is smaller for the same magnetic strength, and it is more easy to render the combination astatic. The shape of the magnetic system is such that it is not so liable to be affected by mechanical vibrations.

G. J. B.

New Type of Shallenberger Alternating-Current Measuring-Instruments.

(The Electrical World, vol. xxv. 1895, p. 28.)

The introduction of multiphase currents has necessitated instruments for their measurement, and Mr. O. B. Shallenberger has devised a volt-meter, an ampere-meter, a watt-meter, and a watt-hour meter, which, though primarily designed for the Niagara Station, are adapted to both multiphase and simple alternating currents. Though intended chiefly for commercial use, their accuracy is said to be such that they are adapted to laboratory work.

The watt-hour meter comprises a thin aluminium disk, free to revolve between coils placed above and below it. The upper one is connected through a non-inductive resistance as a shunt to one circuit in two-phase transmission, the lower coils in series in the other circuit. The currents in the two sets of coils are thus in quadrature when there is no lag in the work circuit, and would be in phase if the lag were 90°. The torque on the disk is proportional to the sine of the angle of lag between the currents in the meter coils; and since this angle is complementary to the angle of lag in the work circuit it is proportional to the cosine of the latter angle, and therefore to the power factor. The torque is also proportional to the product of the shunt and series currents and hence it varies as the power transmitted. The motion is retarded by a copper disk revolving in the field of a permanent magnet. The retarding force is proportional to the speed and hence the speed varies as the power. The number of revolutions per minute at full load are from 40 to 50, and it is said that 1 per cent. of the maximum capacity is measured accurately. When used for three-

phase circuits the shunt coil is connected across two branches of the circuit and the series coils in the third branch. As in the last case, therefore, the shunt circuit is in quadrature with the main circuit, although the currents in the three branches differ by 120°; the action of the instrument is thus the same as before. If greater accuracy be desired two or more branches of a multiphase circuit are connected to corresponding series coils, but this is unnecessary when the balancing is good, as in the case of a motor.

A watt-meter is made on the same principle, the disk, instead of revolving, being deflected against the opposing force of a spiral spring. The copper disk, moving in a magnetic field, serves to damp the oscillations and so render the instrument dead-beat. The scale is in the form of a band round the edge of the disk, and the divisions are large.

Volt-meters and ammeters are made in the same manner. In the former case the two sets of coils are in series respectively, with a non-inductive and an inductive resistance giving a lag of nearly 90°. An air-gap in the magnetic circuit of the latter prevents high magnetisation and makes the induction proportional to the magnetising current. The current through each coil is thus proportional to the potential difference, and the deflection is therefore proportional to the square of the potential. The ammeter is said to be a modification of the volt-meter, the coils being adapted to larger currents and lower potentials. At Niagara transformers, specially wound to introduce no errors from change of phase, will be used in conjunction with the instruments so as to avoid dealing with high potentials or large currents.

A watt-hour meter of the same type adapted to ordinary alternating currents has also been devised. In this a coil of high self-induction is substituted for the non-inductive resistance in the shunt circuit, the current in which lags nearly 90°, and the torque is therefore proportional to the power factor. Great care is taken in designing the self-induction coil, and the iron losses are extremely small. The magnetic resistance of the coil is very nearly that of the air-gap left in the magnetic circuit, and it is said that the same meter may be used for either 50-volt or 110-volt circuits with an error of only 1 per cent. The instrument is independent of the periodicity and of the wave-form within ordinary limits. A 50-light meter starts with 0·2 ampere, and at 0·5 ampere it is practically correct; it will revolve continuously at as low a rate as 1 revolution in fifteen minutes. The instrument is not affected by temperature, and only about $\frac{1}{2}$ watt is consumed in the shunt circuit.

C. H. W.

The Callender Automatic Telephone-Exchange System.

(The Electrical Engineer, New York, 1895, p. 26.)

The maximum number of telephones which are in use at one time is only about 20 per cent. of the number connected to an exchange, and the system described provides switching mechanism for the estimated maximum number of lines in use at once instead of for all, the whole of the apparatus being thus common to all lines. Since the duration of the operations of calling the exchange, connecting two lines and ringing up subscribers is short, a small number of pieces of mechanism will suffice, while those in use during a conversation must be relatively more numerous since they are in use for longer periods. As soon as a piece of apparatus has fulfilled its function for one subscriber it becomes immediately available for another, and means are provided for receiving any number of signals simultaneously up to the estimated maximum; also, a call is "stored up" for a short time.

At the subscriber's station, in addition to the transmitter, receiver, battery and bell, is fixed a special apparatus comprising an insulated cylinder free to revolve, carrying ten contact strips of varying length. Against the cylinder press ten brushes, one of which makes contact with ten of the strips, the next with nine, and so on to the last, which only touches one when the cylinder is rotated. In connection with the cylinder are a number of ten-way switches worked by hand, each indicating the numerals from 0 to 9. As many of these switches are provided as there are figures in the highest number connected to the exchange. The cylinder revolves as many times as there are switches when a signal is sent (a preliminary revolution being made in order to acquire the necessary mechanism at the exchange). A commutator revolving once while the other cylinder revolves two, three, or more times, as the case may be, puts the line through the several switches in turn. The cylinders are caused to revolve by pulling down a lever which winds up a spring driving them by gearing controlled by a fan.

When a subscriber is required the switches are turned so that they point to the figures forming his number, the first pointing to the hundreds, the second to the tens, the third to the units, for example; the lever is then pulled. The preliminary impulse causes the line calling to be connected to one of a number of connecting strips in the following manner:—A group of subscribers' lines are connected to a series of brushes which press against a cylinder and also to a number of plungers set round concentric metal strips. On the cylinder are fixed a number of spiral conductors (say four) which are connected severally to electro-magnets, passing one over each group of plungers; the cylinder and magnets are rotated by a motor and are so geared together that when a given line is connected through the cylinder to an electro-magnet that magnet is over the plunger corresponding to the line, and if an impulse is received the plunger rises and connects the line to one of the concentric rings. This apparatus is known as a "circuit

selector." When this occurs a progressive switch is connected in circuit, and is at the same instant moved forward a step, with the result that the signalling line is isolated.

The signalling impulses which follow the first pass first through a "numerical separator," the office of which is to distribute the signals to separate receivers for the figures representing hundreds, tens and units. It comprises an electro-magnet with two vibrating-reed armatures having different periods which vibrate for a definite time when the circuit is closed through the magnet coils. The separator is normally in series with the first receiver, and when the shorter reed comes to rest it closes a circuit for switching the impulses through the next receiver. The longer reed then comes to rest and closes a shunt circuit, which releases the separator and places it in series with the second receiver, and so for the third and others if there are more. The signals are separated by a time interval of about two-fifths of a second to admit of the above operations. There are as many receivers as there are digits in the highest number connected to the exchange, and each consists of a step-by-step arrangement which can take ten forward steps and so record the number of impulses received; each controls ten fractional branch circuits. These circuits are combined by the "numeraliser," and a circuit is selected by it equal in numerical value to the combined indications. As soon as the number is registered a second progressive switch, forming a pair with the one controlled by the "circuit selector," is brought into play and prevents the line required being connected to any but the subscriber calling. The first progressive switch has now moved forward another step connecting the line to the "signalling track," which consists of two copper rails insulated from one another, one is continuous, the other broken up into sections; the former is connected to an alternating current generator, and when a copper ball is discharged along the track on the registration of a signal it connects it to the different sections of the other. Where the ball rings the bells the divided rail is in three parts; if the connection is made all act as one and a long continuous ring is given, but if the line required is engaged the middle section is neutral and two short rings are given. The "connector" which puts the line required in connection with the one calling is a counterpart of a portion of the "circuit selector." The connector is set free by a release impulse from the signalling transmitter or by a time limit apparatus; each of the other instruments has been set free for the use of other subscribers immediately it has fulfilled its own functions.

If desired, calls may be stored up if a line wanted is engaged, the line being connected as soon as it is free; many calls may be stored for the same line. The same inventor has devised a method of recording the number of connections made to a subscriber together with the hour and date of the connection; this provides a means for encouraging the use of the telephone during hours when there is little work by reduced rates for calls registered during those hours.

C. H. W.

Municipal Electric-Light Stations. By Max Meyer.

(Elektrotechnische Zeitschrift, 1895, p. 26.)

The question of municipalities being able to operate electric-lighting stations at a reasonable profit is apparently not yet settled in the affirmative (so far as Germany is concerned) in the minds of many critics, and the Author offers in this article some tables based on official statistics to prove that the results obtained in these departments of municipal enterprise have on the whole exceeded expectation. The first of these tables shows the rapid growth of electric-lighting in a number of towns during the past five or six years, the following being a selection :—

Town.	Number of Inhabitants.	Total Capacity of Station : 16 c.p. Lamps Burning simultaneously.	Lamps Installed.						
			1889.	1890.	1891.	1892.	1893.	1894.	Dec. 1894.
Aachen .	100,000	8,300	..	..	..	..	8,000	..	11,600
Altona, including St. Pauli	143,000	11,000	..	..	..	1,500	4,300	7,300	9,300
	..	2,500	.	..	..	..	400	2,500	2,700
Barmen .	116,000	6,000	..	5,000	..	6,970	7,490	..	10,500
Cassel . .	75,000	..	..	..	..	4,400	5,300	6,400	
Düsseldorf.	145,000	14,000	..	..	..	..	17,750	19,200	21,200
Elberfeld .	132,000	9,000	2,500	3,360	4,770	6,490	8,550	10,050	11,100
Hannover .	164,000	15,000	..	..	8,600	12,900	14,800	..	22,000
Köln . .	299,000	..	..	..	..	10,700	15,300		
Lübeck .	70,000	..	2,950	3,150	4,200	4,750	5,600		

Some of the financial results from a few of these or similarly situated stations for the year 1893–94 are given in Table No. 2.

Table II.

Town.	Capital.	Receipts.	Percentage of Receipts to Capital.	Expenses.	Percentage of Expenses to Capital.	Surplus.	Percentage of Surplus to Capital.
	£	£		£		£	
Altona . .	68,364	8,619	12·6	3,453	5·5	5,166	7·5
Barmen. .	44,266	5,200	11·7	1,814	4·1	3,386	7·6
Breslau. .	75,098	18,006	23·9	6,774	9·0	11,232	14·9
Cassel . .	40,716	5,336	13·1	1,678	4·1	3,658	9·0
Düsseldorf .	117,459	11,647	9·9	3,454	2·9	8,193	6·9
Elberfeld .	66,743	9,438	14·1	4,136	6·2	5,302	7·9

The third table shows the reduction in price to consumers per kilowatt-hour effected in the leading stations when once firmly established. Thus in Berlin the charge per unit has been reduced

by one-seventh for current supplied for lighting-purposes, with an additional reduction also in the standing annual cost per glow-lamp installed, this latter being now only 1*s.* as compared with 6*s.* in 1885. Similarly, the charge for current intended for power purposes in this city is now only one-third of the rate at first enforced.

F. B. L.

Theory of Public Lighting. By André Blondel.

(Le Génie Civil, vol. xxvi., 1895, p. 212 *et seq.*)

This series of five articles form the first part of a dissertation on the use of electric arc lamps for public lighting. They discuss the question of what distribution of light is to be aimed at, and the position in which lamps should be placed to obtain the best effect from them; the second section will discuss the construction of the lamps and optical apparatus.

Attention is first called to the remarkable and rapid growth of the public demand for more brilliant illumination of the streets in all large cities of the civilised world, and the necessity that hence arises for a careful study of how this demand is to be satisfied with a due regard to economy. In studying the theory of the distribution of light, both the physical and the physiological conditions have to be considered, the latter of which are often neglected.

Beginning with the physical conditions, the Author adopts the "pyr" ($\frac{1}{1\cdot08}$ of the English candle, or $\frac{1}{9\cdot62}$ of the carcel) as the unit of luminous intensity, and uses the term "flux" for the total amount of radiation in any solid angle included by radii drawn from the source. The unit of flux is the "lumen," being the flux from a source of light whose intensity is 1 pyr in the unit solid angle. The "illumination" of any surface from a given source is the ratio of the flux across the area to the area itself, and the unit illumination, being that given by 1 pyr on a surface of a square metre placed normally at a distance of 1 metre, is called a "lux." The illumination of any small surface is proportional to the cosine of the angle between the rays and the normal to the surface. Knowing the manner in which a given lamp radiates its light in various directions, it is easy to draw curves giving the illumination from that lamp at various points of a given plane, as, for instance, the illumination of the horizontal surface of a road from a lamp at a given height above it.

By drawing such curves the height of lamp above the road can be decided which gives the maximum illumination at a given horizontal distance from the foot of the lamp. According to this method it is found that the greatest illumination of a horizontal plane, at a distance l (horizontally) from an arc lamp, is given

when the lamp is at the following heights above the plane, namely:—

Arc light, naked	$l \times 0{\cdot}95$
„ in ground glass globe . .	$l \times 0{\cdot}85$
„ in opaline globe . . .	$l \times 0{\cdot}85$
„ in opal globe	$l \times 0{\cdot}50$ to $0{\cdot}80$
„ in holophane globe . .	$l \times 0{\cdot}50$

These are considerably lower values than are given by the old formula $\frac{l}{\sqrt{2}}$ for all cases.

To estimate the illumination of a street surface from a given combination of lamps, the method of tracing curves of equal illumination, or "iso-lux" curves, is recommended. These can be produced from the curves above described, which give the horizontal illumination due to each lamp separately, by drawing a series of circles round each lamp, which are the iso-lux curves for that lamp alone; the intersections of any two sets of circles give a series of points at which the illumination due to two lamps together is known by simple addition, and iso-lux curves for the joint effect of the two lamps can be thus drawn by inspection. This process can be continued as far as necessary; but lamps at more than a certain distance, say 90 yards, may be neglected.

But, besides the horizontal illumination of a roadway, the illumination of vertical planes is not to be neglected. It is true that in many cases if the first object be adequately obtained the other will follow *a fortiori*; but in other cases this argument fails, and two methods, giving equally good results as regards minimum horizontal illumination, may differ markedly in the minimum vertical illumination they give.

No advantage is to be gained by studying the "normal" illumination, *i.e.*, the illumination of surfaces everywhere normal to the rays. In determining the basis of any scheme of public lighting it is very important to come to a clear understanding of how the useful effect of the installation is to be measured. It was at one time considered sufficient to demand a minimum horizontal illumination over the whole street surface. Weissenbruch showed that this practice was objectionable, and proposed to measure the effect by the mean illumination of the surface. This is shown to be the same thing as the total luminous flux across the surface divided by the area of the surface. The method of calculating this for a given arrangement of lamps by using curves of iso-lux is described and illustrated by an example. Wybauw introduced into this method a new idea in treating all the surface within a cone of 45° from the vertical of the lamp as having the same illumination as the edges of the cone, on the ground that the superior illumination within the cone is wasted.

The weak point of the method of mean horizontal illumination, is its neglect of the value of all light which does not fall on the street surface. Now the illumination of buildings, moving objects, &c., is largely effected by rays which do not fall on the street

surface, and such rays serve the purposes for which public lighting is established as much as those which do fall on the street surface. In many cases the Author thinks that all the light emitted in the space below the horizontal plane through the source may be considered useful.

If the value of the system is to be judged by horizontal illumination only, the solution which at first sight might seem the most natural to attempt is that of a uniform distribution, and a dioptric apparatus for attaining this result was constructed by Mr. Trotter in 1882.[1] It was found that in the present state of manufacturing resources uniform illumination could not be successfully realised, and a closer study of the public taste shows that, if attained, it would not give satisfaction. Certain spaces brilliantly lighted are a desideratum, and the loss of these would not be compensated by the small increase in the minimum illumination gained by a uniform distribution.

The best theoretical curve of distribution, in the Author's opinion, for an individual lamp, is one giving uniform vertical illumination at a greater angle than 45° from the vertical of the lamp, and uniform radiation in all directions within that angle. This could only be realised by optical methods to be described in the second section. If no optical apparatus is used, something may be done to palliate the losses due to the uneven distribution from the natural arc light by a wise choice of the height of the lamps and of the distances between them. Uniformity is improved, and at the same time the minimum horizontal illumination at a distance is increased, by very high lamps, and this consideration formerly led to the use of lamps at 100 feet or more above the roadway in some places, chiefly in America. These advantages are only gained by the sacrifice of others more important. Thus, much of the light with these very high lamps is sent out too high to serve any useful purpose; the slightest fog causes immense loss by absorption; the mean illumination diminishes, although the minimum at a distance increases; and finally, the vertical illumination becomes very bad. In exceptional cases, however, as, for instance, where the surrounding buildings are high enough to distribute the light by reflection, this method may be advisable.

Experience seems to show that in general the height should be between 5 metres and 10 metres, the most usual height in France being 6 metres or 7 metres (20 feet to 23 feet).

The best position to adopt for the lamps in all respects is along the middle of the street, the spacing in wide streets being not less than the width of the street, and in narrow streets being not less than 80 feet, and the power of the lamps being determined so as to give the minimum illumination desired. Where this arrangement is impossible the method of placing the lamps at the edge of the footways and alternately on the two sides of the road is resorted to; but for wide streets a better result would be obtained

[1] Minutes of Proceedings Inst. C.E., vol. lxxviii. p. 346.

for equal expenditure of energy by placing the lamps in pairs opposite each other, and halving the current of each lamp. Several examples from different towns are represented by diagrams.

As regards the power of the lamps, the Author thinks that the supposed economy of powerful lamps has been overrated, and that a greater number of smaller lamps would often be more economical.

Hitherto in France arc lamps have always been made to consume 10 amperes or upwards of current. The Author thinks that in many towns lamps of 5 amperes or 6 amperes would be more suitable, and quotes the contract of the city of Milan with the Edison Company to show that the cost per lamp-hour is nearly proportional to the current of the lamp. The payments agreed are 2*s.* 3*d.* per lamp-hour at 4½ amperes, 3*s.* 3*d.* at 10 amperes, 7*s.* 1*d.* at 20 amperes, and 14*s.* 2*d.* at 40 amperes. With alternate currents, however, it is not desirable to go below 8 amperes, and they do not work to the best advantage at less than 10 amperes to 15 amperes.

The physiological phenomena to be considered in connection with arc lighting are two, viz., (1) the property possessed by the pupil of the eye of contracting or dilating to regulate the quantity of light admitted to the retina, and (2) the effect of contrast by which the differences of illumination existing between neighbouring surfaces are exaggerated to the eye, the exaggeration being greater as the actual difference is greater. In a good system of public lighting the first of these properties of the eye dictates that only surfaces of moderate intrinsic brightness should be used as direct sources of radiation, and the second dictates the avoidance of contrasts.

The Author concludes that the following conditions may be laid down as the bases of a contract for public lighting:—

(1) A mean illumination on the roadway (or better, of all fixed surfaces usefully lighted) equal to E_m; (2) a minimum horizontal illumination on the roadway equal to E_n; (3) a minimum vertical illumination at a certain height; (4) an excess of horizontal illumination within a circle of say 16 feet radius about each lamp, described at a height of 5 feet above the road; (5) an excellent diffusion of the light, *i.e.*, the use of sources of small apparent brightness and of intensity proportional to the width of the road.

Examples from current practice are given of the constants to be used in these conditions, and diagrams representing by isolux curves the effect of various installations.

Another important question is the basis of payment in a contract for lighting. The earlier system was to pay so much per carcel, a system which gave rise to great misunderstanding; the later system is to pay so much per unit of energy, a system which leaves the contractor without any interest in the efficiency of the lamps by which the energy is made useful.

The method here recommended is to fix a price according to the total quantity of light emitted by the lamp below the horizontal, measured in "lumen-hours." It would be easy to control the

payments by fixing on a type of lamp whose characteristics would be decided once for all before use; the voltage, the intensity of current and size of carbons would, of course, be laid down in the contract. It would then only be necessary, in order to control the efficiency of the work done by the contractor, to verify that those three elements were being correctly maintained and that the lamps in use were of the standard agreed on.

C. F. F.

The Zwickau Electric-Light and Power Station.

(Elektrotechnische Zeitschrift, 1894, p. 686.).

The question of combined working as regards the supply of energy for electric light and power has received a practical solution in several instances, and notably at Zwickau, a town in Saxony of some 50,000 inhabitants. The Author describes in detail the entire installation as employed for electric lighting and traction purposes. The power-house or central station contains plant sufficient for operating at any one time 4,000 glow lamps of 16 candle-power each, and eleven cars on the tramway lines. It consists of a large building at the corner of two streets; along one frontage are the offices and workshops for small repairs, &c., with dwelling rooms overhead; the other frontage includes a three-storey building used for an accumulator-house, together with the main engine and dynamo room—a fine lofty erection covering nearly 4,000 square feet, with a clear height to the iron roof trusses of 23 feet. The boiler-house, coal-store, chimney-shaft, condensing-apparatus, &c., are all placed in the rear of these buildings. Underneath the engine-room is a basement for ready access to the foundations, fly-wheel pits, condenser gear, &c. The boiler-house covers an area of some 3,300 square feet, and is 14 feet high in the clear; three Cornish boilers are at present installed, with room for a fourth, the extra space being meantime used as a coal-store. Each boiler has a heating surface of about 970 square feet, and is designed to work at 140 lbs. steam pressure. The steam-valves, dampers, &c., are all operated by hand chains from a point near the stoke-hole. Feed-water is pumped from a 5-inch bore-hole 120 feet deep into a reservoir on the ground level, thence by a second pump into a filter whence it flows into the feed-water cistern. Two Worthington feed-pumps (one acting as reserve) are used to pump water into the boilers, and the exhaust steam from these various pumps is caused to heat the feed-water by being passed through a steam coil in the cistern. The chimney stack is 138 feet high, with an area at the foundation of 65 square feet.

The steam-engines are of the horizontal coupled compound condensing type with jet condensers; their normal output is 100 HP. each at 135 lbs. steam pressure and 150 revolutions per

minute. The point of cut-off is at $\frac{1}{4}$ stroke when condensing and $\frac{1}{10}$ when exhausting into the air. The output may be increased to 150 HP. with a cut-off at from 0·44 to 0·66 of the stroke. The diameter of the low-pressure cylinders is 18 inches, of the high, 10 inches, the stroke being 21 inches. The condenser (distinct for each engine) is worked from the low-pressure crank-rod. The condensing water is cooled after use by means of cold air from a large centrifugal fan worked by an electric motor. Each steam-engine drives by means of belting a couple of dynamos; the latter are joined in parallel for electric lighting, and in series for the tramway service. The electric-light network is arranged on the three-wire system; the tramway on the simple two-wire parallel. Additions to the plant will include motor-generators or continuous-current tranformers by means of which the machines already installed—with others to be added as the demand increases—may supply current for either the lighting or traction circuits. The generators at present used give an output of 48 kilowatts each, at a normal electromotive force of 250 volts, but the pressure is capable of variation between 220 and 300 volts. The accumulators installed in the power house are of the Hagen type, arranged in two series of 68 cells each; the total capacity is 787 ampere hours, the maximum charging rate being 202 amperes, and the discharge 282 amperes.

The lighting circuit cables have a total length of 34 miles laid in 8 miles of trenches; the furthermost point of the network is about 1,200 yards from the power house, with a maximum drop in potential at full load of 1·5 volt in the distributing mains and 15 volts in the feeders. The cables used are provided with a double lead covering armoured with iron ribbon; the trenches in which they lie are lined first with a layer of sand 4 inches thick, then with a layer of bricks; they usually run under the pathway about a yard distant from the building line. The distributing mains are laid about 18 inches deep, and the feeders 7 or 8 inches below this point. Under the main streets the cables are placed still deeper, viz., from 2 feet 6 inches to 3 feet deep; where it is not possible to set them so low they are run in iron channels with iron plate covers. The lighting arrangements are completed by the provision of pressure-test wires run to different parts of the network with automatic relays in parallel with the voltmeters or pressure recorders. These relays serve to actuate signals by which the attendants are warned when the pressure drops, and at night time they are made to actuate the accumulator switches automatically so as to maintain the pressure constant without skilled or indeed any supervision.

The tramway lines operated from this station comprise two lengths, one of $2\frac{1}{2}$ miles, another of 2 miles. On the former a six-minute service is maintained with nine cars; on the second, a twelve-minute service, two cars sufficing for this traffic. The car speed is maintained at $7\frac{1}{2}$ miles per hour in the town and 9 miles at the outskirts. The line is of metre gauge, with no very severe

curves or grades, the greatest being 70 feet radius and 3 to 3½ per cent. respectively. The trolley system is adopted. The trolley-wire is of silicium bronze, ¼ inch diameter, suspended at an average height of 18 feet 6 inches above rail level, either from bracket poles or cross-span wires of light steel cable. In the town itself the poles where employed are of iron, in the outskirts, of wood; in both cases they are set in concrete blocks 40 inches square 6 feet deep. The length of trolley-wire between supports varies from 125 to 140 feet. The trolley-wire circuit is divided into several sections, each with a distinct feeder cable running to it from the central station. The cars are each provided with two 10-HP. motors, mounted on a four-wheeled truck of 5 feet wheel base. Single reduction-gear is employed working in an oil-box. The cars have sitting accommodation for sixteen passengers, with twelve standing on the platforms; five glow lamps (run in series from the trolley-wire circuit) serve to light the car interior and platforms, but oil lamps are also provided for use when the trolley is off the wire. The supply-station or power house was built and equipped in six months, and the tramway construction work was completed in about the same time. The average number of passengers carried daily is about 4,000, the maximum so far having been 9,000 in one day. Each car has therefore carried about 500 persons per diem, with a mileage of nearly 100—results which could hardly have been obtained, says the Author, with horse traction. The consumption of energy averages 480 watt-hours per car mile.

The article is accompanied by seven illustrations and plans of network, power house, gear, &c.

F. B. L.

Electric Mains in Paris. By A. Monmerque.

(L'Eclairage Electrique, 1894, p. 625, and 1895, pp. 97, 253, &c.)

The Author describes with illustrations the different systems of mains laid in Paris since the commencement of public supply. He gives the reasons why certain types of mains and conduits have been abandoned by the various companies. One section of Paris was first laid with iron pipes and insulated conductors were drawn into them. The injury to the insulation during the drawing-in, and earth contacts in the street wires led to the total abandonment of the mains so laid. The cables required in the same section for charging accumulators in series of 1,500 volts were laid in paraffined wood troughs. The conductors were highly insulated and also lead-covered, and have given very little trouble. Some tension supply-cables were bare conductors insulated in iron conduits by means of paraffined wood and porcelain. These mains were an endless source of trouble, and the damage done by the frequent short-circuits between the con-

ductors and the iron conduit was considerable. The successful bare-main system is one in which concrete conduits are used, the copper strip being supported on glass or porcelain. In narrow streets attempts were made to save space by using porcelain conduits laid in half-yard lengths.

These have given much trouble and have been finally abandoned. After a time a whitish alkaline material was formed in the conduits, consisting not solely of alkaline carbonates but also of pure sodium in sufficient quantities to deflagrate explosively in water.

The Author reviews probable causes for these formations which have necessitated these porcelain conduits being entirely replaced.

Another abandoned conduit system was that of supporting rubber cables by enamelled iron brackets. The insulated resistance was good at first, but, owing to the iron rusting, it fell much below that required by Government regulations within a year of the first laying. The system was abandoned in favour of armoured cables after several attempts to improve the insulation where the cable rested on the iron.

A new system with porcelain insulation instead of iron brackets gave encouraging results, the insulated resistance being raised nearly a hundred-fold.

R. W. W.

The Electric Lighting of Railway Post-Cars. By — POHL.

(Archiv fur Post und Telegraphie, 1895, p. 65. 5 Figs.)

The Author lays great stress upon the hygienic aspect of the question, as the sorters have to travel long journeys by night, and it is essential for the prompt despatch of business that the illumination and atmospheric conditions in the cars should be as perfect as possible. The system in previous use was oil-gas lighting, but this was found unsatisfactory, as the lamps heated the atmosphere too much and there was a great danger of fire being caused. Electric light has the advantage of being unaffected by wind and storm.

The directors of railway companies are well aware of these advantages, and have carried out a number of experiments. The Author then refers to the London, Brighton and South Coast Railway, and states that in 1881 a Pullman car was first lighted on this line by means of accumulators, and that now there are in use forty trains of about 400 cars all lighted by electricity. The first attempt in Germany was made in 1883-4 on the Frankfort-Bèbra line.

The postal authorities were struck with the results obtained, and determined to try electric lighting. At the close of 1893 there were in the Royal post district, 1,578 railway post-cars, besides 906 cars hired from the railway companies. In these 2,484 vehicles there were carried 4,555 posts over a distance of

68 millions of miles, and conducted by 5,070 officials. The bulk of the heavy postal service is carried on at night, and as many as fifteen officials are often at work in one car.

After alluding again to the disadvantages of oil-gas lighting, the Author describes the requirements of a good accumulator. He condemns pasted plates as being too fragile, and prefers the solid plates made by W. A. Boese, of Berlin. These cells were tested by the Telegraph Department in 1892, and have been since then in use for telegraphic purposes. This maker brought out in 1893 a special type for use in the post-cars. Each battery consisted of sixteen cells, each cell containing seven positive and eight negative plates; each plate measured 5·5 inches by 3·94 inches wide by 0·235 inch thick. A satisfactory trial of this battery was made in May, 1893, on the Berlin-Zossen line. Others were ordered, and it was found that after eight lamps of 12 candle-power each had been fed for twenty-four hours, with an output of 192 lamp-hours, the potential of the battery had fallen from 32 volts to 30 volts. From nine to eleven 12 candle-power lamps took the place of eleven to fourteen Pintsch gas lamps. Frost did not affect the working, and at the end of 1894 a total of 405 post-cars had been fitted with electric light, and 204 more cars ordered to be so fitted.

At first the cells were charged at Boese's works and carted 2·8 miles. A battery of sixteen cells then gave 31·7 volts, with a discharge current of 5·5 amperes, after a charge of 130 ampere-hours; 125 ampere-hours could be obtained with a fall of potential of 10 per cent. The fifteen plates were brought down to eleven and afterwards to nine. The sixteen cells are now placed in four boxes of four cells each, and give 32 volts and a capacity of 120 ampere-hours.

A description then follows of the manufacture of the plates, which appear to resemble those known as "Lithanode" in this country. The cells are of glass, 7·8 inches high, 6·9 inches wide, and 4·9 inches deep, each containing four positive and five negative plates. The acid used has a specific gravity of 1,260, and the weight of each cell in working order is 24·7 lbs., of which 6·25 lbs. is due to the glass cell.

Each group of four glass cells is contained in a wooden box, and the space between the cells and the box filled with a preparation of kolophonium, paraffin, and asphalt. A short circuit has never yet occurred.

A table is given in the original from which it appears that the

Gross weight of a sixteen-cell battery	457 lbs.
Average charge and discharge current	6 amperes.
Capacity	120 ampere-hours.
„ per positive plate	13·5 „ „
First cost	£23
Later cost by allowance for old materials . . .	£13 16s.

There are now seven charging stations, six fed from public supply

stations, and one has its own generating plant, consisting of two gas engines and two dynamos. For the complete charge of a battery 5,850 watt hours are required, but as a rule 3,000 to 3,600 watt hours suffice. Two batteries are usually charged in series, and the Author then describes in detail the special switchboard used for charging. This has cost £9 for each battery charging circuit. At Hanover, as the potential of supply is 220 volts, five batteries are charged in series. The cost of energy varies from 1·92*d.* to 2·9*d.* per unit. At the Schlesischen station 3·6*d.* per unit is charged, but as the full potential is used, whereas at some of the other stations there is always a resistance in circuit, the charge is equivalent to 2·9*d.* per unit.

Glow-lamps, known as the "Sirius" type, made by the Rheinischen Glühlampenfabrik at Oberbrück, near Aachen, have proved the best. At 30 volts they give 12 candle-power. The average life per lamp is 211 hours, as measured in the office of the telegraph engineers; the average total light developed is 1,809·6 standard candle-hours, and the average energy received 4,868 watt-hours (including 18 per cent. loss). The price per lamp is 1*s.* Therefore the

		d.
Cost of lamp per lamp-hour	$\frac{12}{211}$	= 0·056
Cost of energy at 1·92*d.* per kilowatt-hour	$\frac{4{\cdot}868 \times 1{\cdot}92}{211}$	= 0·044
Total cost.		0·100

This is reckoned upon the supposition that the lamps are kept in use until each candle-power requires 4 watts to produce it; but if they are only used until the required power is 3 watts per candle-power, then the cost becomes 0·108*d.* per lamp-hour. The cost of the wiring varies with the size of the car from £12 19*s.* to £14 15*s.*, and with the joinery work from £16 1*s.* to £18 1*s.* About 75 per cent. of the cars are only 39·37 feet long and have only five lamps each. With the battery included the cost for such a car is £39 5*s.*, whereas the gas installation cost £39 7*s.* A car 47 feet long with eleven lamps costs with two batteries £64 1*s.*, whereas gas costs £67 10*s.* The weight of the electric installation is 660 lbs. less than for gas in the 39·37 feet car, and 1,210 lbs. less in the 47 feet car.

No definite opinion as to the relative working cost is yet available owing to the uncertainty as to the life of the batteries.

Without allowing depreciation or interest for batteries or charging stations, or service at the latter, the working cost per electric lamp-hour at 1·92*d.* per kilowatt is 0·1*d.* to 0·108*d.*, and at 2·87*d.* per kilowatt the rate becomes 0·122*d.* to 0·13*d.* per lamp-hour. With oil-gas at £1 8*s.* 4*d.* per 1,000 cubic feet (*sic*), as charged by the railway company, the cost per gas lamp-hour was 0·48*d.* to 0·6*d.* If depreciation at 20 per cent. be allowed for the

cells and 10 per cent. for the charging stations, with interest at 6 per cent., then the saving effected by using electricity instead of oil-gas is 21 per cent. The Author, however, does not consider financial considerations of paramount importance in the postal service.

E. R. D.

The Electricity Works at Bremen. By F. JORDAN.

(Elektrotechnische Zeitschrift, 1895, p. 76.)

The public electricity supply works of Bremen comprise four distinct stations, one of which contains the main generating plant, boilers, steam-engines, dynamos, &c., whilst the other three are practically sub-stations provided with accumulators, continuous current transformers or dynamotors, and the usual regulating appliances. One noticeable feature of the general plan adopted lies in the fact that the mains between the generating and sub-stations are laid on the ordinary two-wire principle, whilst outwards from the sub-stations they are run on the three-wire system at 220 volts pressure. At the generating station fuel is brought directly into the coal store from the railway alongside, and thence taken into the boiler house on small, narrow-gauge trucks or wagons. Steam is obtained from three water-tube boilers, each with a total heating surface of about 1,890 square feet, and designed for a working pressure of 170 lbs. to the square inch. The Author describes at length this design of boiler, tracing out the sequence of water and steam. A double ring main of steam-pipes leads from the boilers to the engine-room, and valves are provided in the usual way to allow any of the engines to take steam from either side so that repairs may be effected without complete stoppage. The engines are of the triple-expansion marine type with surface-condensers built into the base-plates. In case of failure in the water supply required for surface condensing the steam-piping is also arranged for jet-condensation or direct atmospheric exhaust. Each engine is designed to give a maximum of 320 HP. at 120 revolutions per minute and at a steam pressure of 160 lbs. in the high-pressure cylinder. The latter is provided with piston-valve gear and a variable expansion; the middle and low-pressure cylinders have fixed expansion gear with plain slide-valves. The condenser air-pumps are driven direct from the engines, a supply of water being obtained for condensing from two tube wells each 31½ inches diameter with a capacity of 24,500 gallons per hour. This is forced by centrifugal pumps operated by electric motors into three large tanks above the engine and dynamo room whence it flows to the condensers by gravity. The engines are directly coupled to dynamos of the interior-field overhung type, each giving an output of 211 kilowatts (680 amperes at 310 volts). From the generating-station mains are taken to the distributing centres—one

of these being 2 miles distant—serving the residential quarter. In each of these centres or sub-stations are placed two continuous-current transformers or dynamotors for charging the station accumulators. One of these serves for ordinary working, the other being kept in reserve. Two motors coupled in series across the three-wire system, one on each side of the middle wire, serve to operate the generator by means of leather-lined friction-couplings, all three machines in each set being mounted on the same foundation. The first sub-station is provided with two batteries in parallel, each of 136 cells, having a discharge capacity of 276 amperes, that is, a total output of about 220 HP. Stations two and three have each a battery of 136 cells with a discharge of from 96 to 193 amperes. Automatic regulation is provided in order to dispense as far as possible with continuous skilled attendance. The day's work is usually divided into three portions: 1st, charging; 2nd, dynamos and accumulators working in parallel; 3rd, discharge (dynamos cut out). The network of mains is calculated for a total capacity of 20,000 lamps (each of 16 candle-power) burning simultaneously; it comprises a total length of 130 miles of iron-armoured lead-covered cable laid under the footpaths, as a rule on both sides of the streets, at a depth of 27 to 30 inches. At the beginning of January, 1895, there were 26,000 lamps connected to the supply works, 10,000 of these being in dwelling-houses; 500 arc lamps taking an average of 6 amperes each; thirty-four electric motors of a total capacity equal to 100 HP., and a few small motors used for ventilating purposes. The proportion between maximum simultaneous load and output represented by the number of lamps, &c., connected up is found not to exceed 40 per cent.

A number of illustrations and diagrams accompany the text to show the various details of the plant, apparatus and buildings.

F. B. L.

Electrical Distribution of Power at Lunéville.

(L'Electricien, 1895, p. 183.)

A system of distribution of power has been fitted up at the saw-mill of Messrs. Dietrich and Co. at Lunéville. The power is transmitted from a steam-engine by a 53 K. W. Pieper dynamo running at a speed of 630 revolutions, placed in the generating shed some 220 yards from the saw-mill. In the saw-mill there are four motors, each taking about 10½ HP. for driving the various circular, rack, and band saws. A 5-HP. pump placed on the banks of the River Meurthe, 870 yards away, is worked from the same source of power, as is also a blower for forge purposes worked in a building near the generating plant. This fan takes about 21 HP. The voltage at the dynamo is 125 volts, and the current varies with the number of saws at work from 150 to 425 amperes.

The efficiency of the whole system works out as follows:—

Machinery Driven by Motor.	Useful Power Developed.	Efficiency of Motor.	Watts Required by Motor.	Loss in Line.		Power Required from Dynamo.
	B. HP.	Per cent.		Volts.	Watts.	Watts.
Large circular saw .	10·5	86	9,000	5	375	9,375
Rack saw . . .	10·5	86	9,000	5	375	9,375
Band saw . . .	10 5	86	9,000	5	375	9,375
Circular saws . .	14·2	87	12,000	5	500	12,500
Pump	5·0	82	4,500	20	860	5,375
Blower	22·0	88	18,300	3	450	18,750
Total . .	72·7	..	61,815	..	2,935	64,750

The cost of up-keep is only given for the pump-motor, and this is compared with the previous annual cost when the pump was driven by steam.

	Present Cost.			Previous Cost.		
	£	s.	d.	£	s.	d.
Coal	14	8	0	96	0	0
Attendance		..		38	8	0
Oil and up-keep . .	8	8	0	45	12	0
Total . . .	22	16	0	180	0	0

The efficiency of the whole system is taken as the ratio of the B.HP. of the engine driving the dynamo to the B.HP. given to the saws, &c. This works out to 67 per cent.

The article is illustrated.

R. W. W.

Electric Motors in a Sugar Factory. By O. KÖHLER.

(Elektrotechnische Zeitschrift, 1895, p. 69.)

The Author gives some particulars with regard to the use of electric motors in the Groningen sugar factories. The generating plant employed is situated about ½ mile from the works themselves, and it comprises two continuous current dynamos (one of 42 kilowatts, the other of 23 kilowatts output) driven by turbines. In the factory there is a battery of accumulator cells, 120 in number, of a capacity equal to 594 ampere-hours. The main electric motors in the factory are two in number, separate steam-engines being also installed as a stand-by or for occasional use. The generators furnish current for 750 glow lamps and ten arc lights as well as for the two large motors, and five other smaller motors of a total capacity of 25 HP. The latter have served to replace several small steam-engines with countershafting, and have been working for two years with great success.

Economy has been particularly noticeable in the case of a hoist, where a saving of 33 per cent. in the energy spent on frictional losses, &c., has followed from the use of electricity. The main shafting formerly employed took 4·25 HP. to drive unloaded, 6·5 HP. with the driving gear for six centrifugal machines, and 7·5 HP. with the same for twelve machines. Each of the latter requires about 1 HP. to maintain full velocity, but from 4 HP. to 10 HP. is necessary to bring them up to speed, dependent of course upon the time occupied. For the large centrifugal machines a 35 HP. motor is used; the diameter of each machine is 2 feet 7½ inches, with a capacity of 5 cwt., they are run at a speed of 950 revolutions per minute. The shafting and gear for the eighteen large centrifugals alone, at a speed of 160 revolutions per minute, is stated to have required 15 HP.

A series of careful experiments made with these machines showed that about 5 HP. each was necessary to maintain the speed, as much as 27 HP. being required at first to develop the proper velocity for a 60-seconds' duration of work.

The Author concludes that no more need be said to show how great a saving may be effected by direct coupling of motors, as compared with belt-driving or the use of heavy countershafts and similar gear.

F. B. L.

The Thiergarten Accumulator Sub-Station, Berlin.

By Emil Rathenau.

(Elektrotechnische Zeitschrift, 1894, p. 652.)

The Thiergarten quarter of Berlin comprises principally the residental mansions of the upper class of that city, and hence the demand for electric light is wide-spread throughout the entire district. When current from the Berlin electricity works first became available for lighting purposes the almost universal service at once required in the Thiergarten quarter made it necessary to arrange for additional plant, and after careful consideration of the attendant circumstances it was decided to follow the plan of a large accumulator-sub-station operated from the nearest of the four large electric generating stations under the control of the Berlin Electricity Supply Company. The distance from the centre of supply in the Thiergarten district to the nearest generating station—in the Mauerstrasse—is in round figures 1¼ mile, and in view of the heavy demand spread over a short period of the day it was decided as mentioned to put down accumulators rather than employ transforming devices to maintain the pressure in the newly opened-up district. The distribution generally throughout Berlin is on the three-wire system, but for connecting the new district sub-station with the Mauerstrasse generating station the two outer wires alone are used. In the Mauerstrasse station are large

supplementary dynamos from which is obtained current for the Thiergarten district, designed to maintain the voltage at the higher pressure necessary for the increased distance and area covered, and which are also used for charging the accumulators in the sub-station. The network is calculated for a total of 12,000 lamps alight simultaneously, which allows of about 50,000 being connected up to the mains, since not more than one-fifth or one-fourth of the number is required at any one time. The drop in pressure is stated to be 20 volts under such conditions between the outer mains of the three-wire system. The Author gives a load curve showing the consumption at the sub-station during a heavy twenty-four hour period. The lamps run were 9,000 in number, each taking 0·46 ampere at 108 volts. A maximum (at the above output) of 650 amperes is required from the central station mains and a maximum of 1,420 amperes from the accumulators. The capacity of the latter is 6,094 ampere-hours. An average of 828 amperes into the battery and lighting circuits (in parallel) would charge the former sufficiently for the usual heavy discharge between 5 P.M. and 10 P.M. and so give a continuous straight line for the load curve, thus avoiding the usual 7 P.M. heavy "peak" in the diagram. The supplemental dynamos already mentioned as being erected in the Mauerstrasse central station for charging these accumulators and raising the pressure have a capacity of 800 amperes, so that from 9,000 to 10,000 lamps may be run simultaneously either direct or through the accumulators. The latter are of the Hagen type, 138 in number, these are arranged in two rows of fifty-eight each, the remaining twenty-two being placed on an upper floor of the accumulator house, in two rows of eleven each, for regulating-purposes. The cells measure outside 3 feet 10 inches long, 19½ inches wide, and 2 feet 11½ inches deep, and weigh in working order not less than 1¼ tons each. The cost of this extension as at present installed is given as follows :—

	£.
1. Accumulators, switch boards, &c.	7,400
2. Supplementary dynamos with switch gear, &c. . . .	1,500
3. Mains, both distributing and connecting	27,250
4. Buildings, &c.	2,500

or a total of £38,650. To bring the equipment up to the full capacity of 50,000 lamps wired would, however, require the outlay of £6,750 in addition, making in all £45,400 for the completed sub-station.

Six diagrams and illustrations accompany the article.

F. B. L.

Accumulator Tram-cars at Hagen. By C. P. Feldmann.

(Elektrotechnische Zeitschrift, 1895, p. 37.)

A short length of tramway was opened early in the present year at Hagen, in Westphalia, where the line traverses the most important streets for a length of 2 miles. The line is of metre gauge; the sharpest curve has a radius of 46 feet, and the steepest grade is 4 per cent. The cars, which run at an average speed of 7½ miles, and a maximum of 10 miles per hour, are five in number, with accommodation for 26 passengers, twelve sitting and fourteen on the platforms. Each car is fitted with a 15 HP. motor and a set of accumulators (88 cells) under the seats. These accumulators are of the Waddell-Entz pattern, employing zinc and copper elements; each cell has seven negative and six positive plates, weighing with the liquid electrolyte, &c., in working order about 28 lbs. The electromotive force of each cell is from 0·85 to 0·88 volt, and the normal capacity about 250 ampere-hours rising to a maximum of 300. This gives a charge per battery equal to 21 car miles for average working. The weight of the battery complete in position is about 1½ tons, and that of the entire car, when loaded, about 7 tons. The speed reduction between motor and car axle is obtained by means of toothed gear, arranged with a ratio of five to one. Twelve cells of the battery are reserved for exciting the motor fields, being shunted through a resistance when the speed exceeds 7½ miles per hour. These cells are also used for lighting five lamps, each of twelve candle-power, placed on the platforms and inside the car. The remaining cells, 76 in number, are arranged in four sets so as to be coupled all in parallel, two in parallel and two in series, or else all in series. The regulating appliance or controller is practically a multiple switch with eight contacts. When running, the motor-man throws the handle over from the zero point (current cut off) to contact No. 2 (four rows of cells in parallel), then gradually turns it on to 3 (two in series two in parallel) and 4 (all four in series), the latter combination representing the normal speed. Contacts Nos. 5 and 6 throw an increasing amount of artificial resistance into the field circuit. Contact No. 1 is arranged to reverse the action of the motors, converting them into generators driven by the momentum of the car, and thus acting as a powerful brake. The current so generated is absorbed in the accumulators in much the same fashion as with railway trains lighted by electricity, from a dynamo and accumulators in the guard's van. The braking effect of thus changing the motors into generators is very great; but as an additional precaution ordinary chain brakes are also employed. The electric brake is arranged to act automatically when the normal speed is exceeded by 15 per cent. The charging station is on the ground floor of the Hagen accumulator factory; a special switch-board is provided on a side wall, with space in front for the track on which the cars may stand. The batteries to be re-charged (each

group of forty-four cells in a wooden framework) are placed on a level with the car truck over a coil of hot-water pipes arranged to keep up a temperature of 50° in the electrolyte. The initial pressure of charge is about 0·9 volt per cell, rising to 1 volt at the end of charge. A small transfer table worked by hand is arranged so as to run alongside the cars, the top of it being on the same level as the bottom of the car-body. The batteries may thus be drawn out from under the car-seats on to the table, which is then pushed up to the charging tables and there unloaded; the reverse operation of course takes place when the batteries have been charged and are ready for use in the cars. The weight of these batteries for equal outputs is claimed to be 0·55 only of the weight of similar batteries constructed on the lead-oxide paste principle.

F. B. L.

Electric Traction on Canals. By A. de Bovet.

(Mémoires et Compte rendu des Travaux de la Société des Ingénieurs Civils, January, 1895, p. 40.)

In ordinary canal navigation it is generally impossible to tow a string of barges owing to the difficulties that would arise at the locks. Haulage by horses is the only method that has so far been found to answer to the economical requirements on any large scale. As an instance of the cheapness of transport by horse traction, the canal of St. Quentin is quoted, on which the charge for traction is 0·0474*d.* per ton-mile, the work being done by contractors, each working a section of the canal 8 to 11 miles in length. The prescribed speed is 1¼ mile per hour.

Nevertheless, numerous attempts have been made of late years to introduce mechanical traction on canals. The benefits to be expected from such a system, if successful, are an increase of speed up to 1½ or 1¾ mile per hour, a greater regularity of service, with saving of time now wasted in stoppages, and a possible small saving in cost per ton-mile.

The Author considers it obvious that no method which requires the barge to be self-propelling, *i.e.*, to carry a steam-engine or other prime motor, can have a chance of success, and thinks it also clear that small tug-boats could not be used, chiefly because each barge is built so as to completely fill the lock by itself. Any system to be economically successful must be able at any point of the canal to supply a barge with power equal to 2 or 3 HP. effective, and the available tractive force at the locks must be greater than in other parts, even if the speed is reduced. After reviewing the various methods that have been proposed, answering to these requirements, he proceeds to describe the electric system, with which he has himself made experiments on a practical scale. These experiments were made on the St. Denis Canal, the machinery being supplied by the Fives-Lille Company.

The system used is an adaptation of the "trolley" system used so largely in America for tramways. The towing apparatus is portable and is placed at the forward end of the barge, clear of the cargo. It consists of a motor revolving at 1,000 revolutions per minute and driving a chain-drum by means of two gears, one of which is a friction-gear. Two fixed chains are laid along the bed of the canal, one for each direction of travel. The small pulley on the motor-shaft which drives the counter-shaft by friction, and also the chain-drum, are magnetised by electric coils in order to increase the adherence.

With a chain-drum of 15¾ inches diameter making 40 turns per minute, and the chain (which weighed 10 lbs. per yard) in contact over 180 degrees, it was found that a tension of nearly ½ ton was supported without slipping of the chain. The exciting bobbin of the electro-magnet had 2,450 turns of wire with a current of 2 amperes and a total resistance of about 30 ohms.

The trolley consists of a small two-wheeled truck running above the line-wire and maintained in position by a counterweight hanging below it. The trolley is drawn along by a conducting cable hanging between it and a pulley attached to the mast of the barge. The trolley wheels are fitted with an internal brake which prevents the trolley from running away where there is a steep descent of the cable. The method used on tramways of having a trolley running beneath the cable would be highly inconvenient on a canal. The switch-board for starting, stopping, or reducing speed would in practice be placed within reach of the man at the helm, who would often be the only man on board the barge. The experiments were made with a barge carrying over 300 tons, both loaded and light. A line was established with a copper wire 0·315 inch in diameter on posts placed beside the towing-path. Its length was 437 yards. The current was supplied at a pressure of 110 volts. In practice a higher pressure, say 500 volts, would be used. It was at once found that the chain could not be used to complete the circuit owing to its enormous resistance. A second line was added, with a second trolley drawn by the first one, and with this alteration the expected results were fully realised. The normal speed of 1·7 to 1·8 mile per hour was attained in a distance of under 90 yards. The current was 20 amperes, corresponding to 2,200 watts at the generating station. The trolleys, weighing, one 17½ and the other 20 lbs., gave no trouble and might be made considerably lighter. The apparatus on the barge weighed 2·56 tons and was, for experimental purposes, heavier than need be in practice; 8 or 10 cwts. might be saved on it. The friction-gearing with magnetic adherence has substantial advantages, in starting especially, but these are not thought to compensate for the complication in construction it involves, and worm-gearing is recommended in place of it. Drawings are given of an apparatus of this type as proposed. The two double lines, established one on each side of the canal, should be connected at intervals in order to equalise the flow of current when the traffic in one direction preponderates. A

continuous current is preferable to an alternating current because of the better facilities it affords for starting and for varying the speed. Where water or other motive power is available it may be advisable to generate a high-tension alternating current and transform it down for use, but in general, when steam power is used, it will be advisable to have a station every 7 or 8 miles and generate a continuous current at 500 volts.

Two arrangements are described, and illustrated by diagrams, for obtaining increased tractive force for drawing the barge into and out of locks. On curves of very small radius it is possible that guides for the barges might be necessary, to prevent the chain from getting gradually displaced inwards.

An estimate is given for establishing the system on a canal assumed to be 31 miles long, with four generating stations of 110 HP. each. The traffic is assumed to be 3,360,000 tons per annum, and the number of barges on the chains at once, 125. The estimate works out to £1,600 per mile, and at this cost the Author thinks that a cheaper, as well as more efficient service could be given than with horses. If the traffic were less than that taken as the basis of the estimate, the cost of traction per ton would be heavier, but on canals of small traffic the cost of horse traction also is heavier.

The Author considers that the same system would be applicable in rivers where, by reason of small depth or strong current, ordinary steam-tugs for barges cannot well be employed. A portable engine and boiler with an electro-magnetic towing apparatus might be placed on a barge so as to give a total load with fuel, &c., of not more than 14 to 15 tons, and, a chain being laid in the bed of the river, a cheap and powerful towing system for barges would thereby be obtained capable of ascending against a current of 5 or 6 miles an hour with a load of 300 to 500 tons.

C. F. F.

Electricity Applied to Agricultural Purposes.

(Elektrotechnische Zeitschrift, 1894, p. 603.)

During the summer of 1894 an electric power installation for agricultural purposes was erected by Messrs. Ganz and Co. on a large estate at Jaispitz, Moravia, and the degree of success and economy achieved thereby is thought by the Author to be worthy of note. The source of electrical energy is a large steam saw-mill at one end of the estate. About 30 HP. of the total output of the steam plant is reserved for the electric power transmission, a generator of this capacity being erected in the mill. The electric current is taken thence along two circuits, each about 3 miles long, in directions almost at right angles. One of these circuits is taken to a flour-mill and dairy, with a branch circuit to a neighbouring farm; the second main circuit goes direct to another farm. The

generating dynamo at the power-house is of the continuous-current type, giving 35 amperes at a pressure of 620 volts, and is provided with an automatic pressure-regulator acting in conjunction with a sensitive engine-governor. At the dairy is placed a 10 HP. electric motor driving two centrifugal separators, a pump, and various other appliances; it also serves to operate an adjacent flour-mill to great advantage, for owing to a somewhat limited supply of water the latter could previously only be run by water-power for a very short period in each year.

Each of the farms is provided with a 12 HP. motor mounted on a four-wheeled horse wagon so as to be portable and readily used for thrashing corn at different points on the farm. Bare copper wires overhead are employed for the circuits on the fields, with sliding flexible contacts; the motor-equipped wagons may thus travel along the entire length of overhead conductor to different points where the corn is gathered together into vast heaps for thrashing. The current used at the dairy when at full load averages about 8 amperes, and the flour-mill requires as much more. The current taken by the thrashing machines varies from 10 amperes for pease, beans and other leguminous products, to 14 or 16 amperes for corn. The main conductors are of electrolytic copper, with a diameter of $\frac{1}{4}$ inch, mounted on insulators fixed to wooden posts. On the same posts are erected telephone wires by means of which the generating station and motor stations can communicate with each other. The portable wagon motors, after the harvesting period is over, are employed in pumping or other purposes, and one of them finds useful occupation, when required, in a distillery on the estate. Since the steam plant at the generating station uses up the sawdust and waste wood as fuel, the cost per unit of electricity is little or nothing, so that the entire electric power service is operated at very small outlay compared with what would be incurred by steam thrashing machines of the ordinary type, or fixed steam plant in the dairy and mill.

Two engravings from photographs of the motor wagons and thrashing plant, with a sketch map of the circuits, accompany the article.

F. B. L.

Electrical Cranes at the Havre Docks. By E. DELACHANAL.

(Mémoires et Comptes rendus des Travaux de la Société des Ingénieurs Civils, April, 1895, p. 520.)

After a brief outline of the cost of construction of the Havre docks, and of their equipment of sheds and lifting-machinery, the Author explains the reasons which led to the experiments with electrically-driven cranes, which form the subject of this Paper. The experiments are divided into two sets, the first set being made with four different motors to determine the type most suitable for

the work, and also the chief points to be kept in view in the second set of experiments. The machine used was a travelling crane on a carriage spanning the line of rails next to the edge of the quay, and in construction similar to the steam-cranes used for handling coal at these docks, omitting the boiler, engines, and disk-cranks. The crank-, or first-motion-, shaft rotates only in one direction, the slewing and travelling motions being taken off by means of spur-wheels, and the lifting by means of grooved friction-wheels. The motor was connected to the first-motion shaft.

In the first set of trials the requirements were: (i) a maximum lifting-speed of 2·625 feet per second, with a load of 3,307 lbs., and power to quickly attain this speed from rest; (ii) non-liability to damage from sudden strains; (iii) capability of slewing in any direction with a load of 6,614 lbs.; (iv) the motor to resist motion in a reversed direction; (v) power to raise a load of 3,307 lbs. 32·8 feet high, slew it through 180°, travel 32·8 feet, and return in all three motions to the starting-point in forty-five seconds; (vi) proper protection and easy renewal of the machinery, and construction in accordance with existing regulations.

One series, one shunt, and two compound-wound motors were tried. As their speeds were higher than that of the first-motion shaft of the crane an intermediate shaft was required. The Author then describes the four motors, their electric connections, and their working with the crane under the following conditions:—An empty skip weighing 551 lbs., and a full one weighing 3307 lbs., were in turn lifted to a height of 29·5 feet, slewed through 180°, lowered to quay level, again lifted 29·5 feet and returned to the starting-point, each skip being lifted, slewed, and returned twenty times in the hour. He estimates this at from 40 per cent. to 50 per cent. in excess of the normal work done by similar cranes. Current at 500 volts was supplied for the trials through bare overhead copper wires, 0·031 square inch section, carried on porcelain insulators and telegraph poles. Requirement (v) was satisfied, but the maximum lifting velocity of 2·625 feet per second was not attained. It was considered higher than necessary, and was reduced in the later trials to 2·297 feet per second. Tabulated results are given of the mean of twenty runs with each motor, including the speeds, volts, and amperes, total and useful work, and efficiencies with the various motions. Owing to the rush of current when starting under full load the compound and shunt motors were run continuously. Even with the series motor, the starting current rose to 60 amperes, and, when the resistance was reduced too quickly, to 100 amperes.

On the question of economy, the Author concludes that for electric cranes the first cost is increased, but that with suitable motors, the working expenses may be sufficiently reduced to counterbalance this.

The second set of experiments chiefly consist of trials with a

specially built low-speed series-wound motor coupled to the first-motion shaft through a magnetic friction cone. This motor was run at a maximum speed of from 212 to 350 revolutions per minute, the gearing between the lifting drum and the motor being altered to give the required rate of lift at these speeds. Similar tables to those for the first set of trials are given, and show an improvement on the earlier experiments. Trials with the rheostat showed that the speed of lifting could be varied very widely.

From these trials the Author concludes that electric cranes can be worked as easily as, and—where several are in use—more cheaply than other cranes; troubles from separate boilers and frost are avoided by their use, and also the loss in raising steam; they are also easier to move about the quays. He is of opinion that series-wound motors are most suitable, and that the starting resistance should be provided with a switch to enable the current to be cut off after each motion, and to allow of a wide variation of the speed. A plan of the dock, details of the crane used, and ammeter diagrams of two sets of trials are appended to the Paper.

R. B. M.

Electrical Steering-Gear. By G. Davy.

(L'Electrician, vol. ix. p. 193.)

The Author, after giving credit to Lord Kelvin for the vast improvement made in ship's compasses, describes briefly the disturbing influence to which such compasses are subjected in modern vessels. All means of correcting these influences when the compass is placed in the centre of a ship are more or less faulty, and the Author proceeds to discuss under two heads other methods of obtaining an accurate course.

(*a*) Transmitting electrically the direction of a standard compass, placed in a suitable position not so exposed to disturbing influences, to the man at the wheel.

(*b*) Holding the ship to the course so defined by means of an electric steering-gear, which he calls a *compas-directeur*.

He then describes the methods of steering electrically as devised by Colonel Ballard, in which a deflection from the course causes the compass-card to complete an electric circuit which, by the intermediary action of a steam relay, brings back the ship to its proper course. Besides this English system, an American system of attaining the same object, developed by C. Washburn, is referred to.

All these previous methods are considered by the Author to be imperfect, because continuous currents are carried by conductors on and near to the compass-card, and hence likely to affect its accuracy; also because actual contact between fixed stops and a conductor on the card is required.

The next takes up the gear devised by Lieutenant Bersier, and gives some diagramic sketches of this apparatus.

The essential new feature is the employment of the minute secondary currents of a Ruhmkorff coil to actuate the relay magnets. At the exceedingly high tension employed when the ship falls away from her correct course, a spark can be caused to pass between some conductor on the compass card and one of two fixed plates, no actual contact being required. The sparks passing do not interfere with the freedom of the compass, and the very minute pulsating currents do not affect it. The rest of the apparatus consists of the relay which, when actuated by the small induced currents, puts the motor controlling the steering-gear into circuit; the direction of rotation of the motor being varied in the usual way, according as to which of the two conducting plates receives the spark due to the compass-card moving in its direction.

R. W. W.

The Sag in Span- and Trolley-Wires. By E. A. Merril.

(The Electrical World, New York, vol. xxiv. pp. 569–570.)

The article gives results of tests made by Mr. H. R. Conklin for the Pierce and Miller Engineering Company to determine the height at which the supports of span wires must be placed for a given height above the ground of the lowest point of the trolley wire, the supports having manifestly to be higher than this point by the sum of the sag of the span wire, the sag of the trolley wire, and the distance between the span and trolley wires; this last varies from 2 inches to 5 inches, according to the kind of hanger used.

In the first set of tests a seven-strand galvanised signal strand span wire, $\frac{5}{16}$ inch diameter, was strung up and 125 feet of No. 0 B. and S. copper trolley wire suspended from its middle point by a hanger, the total weight suspended being 42 lbs. The span was varied from 30 feet to 120 feet, and the tension from 250 lbs. to 3,500 lbs. The sag was determined by a surveyor's level. Curves were plotted for every 10 feet difference in span, the ordinates being the sag in inches, and the abscissae the tension in pounds. The empirical formula found to accord sensibly with the curves is given as—

$$D = \frac{l}{S}\left(120 + \frac{l}{2}\right),$$

where D is the sag in inches, l the span in feet, S tension in pounds (between 250 lbs. and 3,500 lbs.).

In the second case the conditions occurring in double track work were reproduced. Two weights, each of 42 lbs., were hung 10 feet apart and equal distances from the supports, the span and tension

being varied as before. The results are plotted in the same manner as in the first case, and the empirical formulas given are—

$$D = \frac{l}{8}(160 + l) \text{ up to 100 feet,}$$

$$D = \frac{l}{8}(150 + l) \text{ from 110 feet to 130 feet.}$$

The sag was next measured in a fixed span of 125 feet of No. 0 B. and S. hard-drawn copper wire, the size usually employed for trolley wires, the tension being varied from 200 lbs. to 2,000 lbs., the highest stress considered safe. The results are plotted in a curve having sag for ordinates and tension for abscissas. This is found to agree approximately with the formula—

$$D = \frac{3\,w\,l^2}{2\,T},$$

where D is the sag in inches, T the tension in pounds, and w the weight per foot, l being the length.

The article concludes with a consideration of the effect of temperature on the sag. This is compensated for by the elasticity of the poles in the case of span wires, but it must be allowed for in the trolley wires. It is assumed that the tension at the lowest temperature is 2,000 lbs., and three curves are given showing the variation in sag with the temperature for three different minimum temperatures, viz., − 10° F. + 10° F. and 32° F. The formula from which these curves are plotted is $D = \sqrt{8{\cdot}1\,t + 14}$ where D is the sag in inches, and t the number of degrees Fahrenheit by which the temperature exceeds that at which the tension is assumed to be 2,000 lbs.

All the curves referred to are illustrated in the article.

C. H. W.

A New Velocity-Recorder.

By J. Alfred Griffiths, B.Sc., Assoc. M. Inst. C.E.

(Proceedings, Royal Society of New South Wales, 1894, p. 281.)

This recorder produces a diagram in which the velocity at any instant is represented by a vertical ordinate on a band of paper moved by clockwork, the horizontal time scale being uniform.

The pen drawing the vertical stroke is moved directly by the prime mover to be recorded through a train of clockwork, which is periodically disengaged at equal intervals of time, so that the pen returns to zero, the length of stroke between each disengagement being proportional to the actual space moved in that interval. By making the time interval sufficiently short the envelope of the

ordinates is a curve of velocity of any desired degree of approximation within practical limits.

The instrument is applied chiefly to anemometry and time intervals of from four seconds to one hour are used. The motion of the time drum may be continuous when the long interval is used, but for a close record an intermittent motion is preferred.

J. A. G.

On the Adhesion of Aluminium and other Metals to Glass.

By Charles Margot.

(Archives des Sciences Physiques et Naturelles, Geneva, 1895, p. 161.)

The Author finds that on heating glass to the melting point of aluminium, the adhesion of the metal is very marked. It is possible to spread the aluminium over the surface of the glass, with an iron spatula. It is suggested that this property may be utilised for cementing together the parts of glass apparatus used in laboratories.

Magnesium also adheres much more easily when heated, but the facility with which it is oxidized renders it less suitable for the purpose, and the same may be said of cadmium. Zinc, at moderately high temperatures, possesses similar properties.

Ordinary plumber's solder, alloyed with a small percentage of magnesium, can be spread upon hot glass like sealing wax; but unfortunately these alloys are speedily attacked by the moisture of the atmosphere.

Tin alloyed with 10 per cent. of aluminium spreads easily, and is more stable, but requires a higher temperature for its use; and an alloy of tin with from 2 per cent. to 5 per cent. of zinc was found to work well.

It is advisable not to raise the temperature too high, otherwise oxidation becomes energetic. An ordinary soldering iron may be used, but an aluminium bit is preferable. No flux is required, but the glass must be perfectly clean.

The Author discusses at some length the probable causes of the adhesion.

G. J. B.

On the Production of Kathode Rays. By Joseph de Kowalski.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxx., 1895, p. 82.)

The Author uses a vacuum tube, shaped like the letter H, consisting of two wide vertical tubes united a little below the middle by a horizontal capillary tube. The electrodes are fused into the upper extremities of the vertical limbs.

When the tube is sufficiently exhausted the electric discharge

causes a luminosity in the bulb containing the kathode, in addition to the light common to both bulbs, and at the same time a pencil of kathode rays is seen to issue from the end of the capillary, striking the opposite wall of the anode bulb and rendering it fluorescent. In another experiment a straight Pflücker tube without electrodes was placed parallel to a Tesla exciter. Kathode rays in addition to the ordinary luminosity were seen to issue from the ends of the capillary, producing fluorescence on the opposite walls of both bulbs.

These experiments show, according to the Author, that kathode rays can be produced without metallic electrodes, and that they are present whenever the ordinary luminosity is of sufficient intensity.

G. J. B.

On a Sensitive Barometer for the Measurement of the Pressure of Fluids. By Paul Charpentier.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxx., 1895, p. 439.)

This instrument may be described briefly as a siphon barometer with wide upper and lower reservoirs and a narrow connecting tube filled with mercury in the ordinary way. But the lower reservoir instead of being open to the air is connected with a tube of fine bore furnished at its base with a three-way cock. A liquid of low specific gravity, such as water or oil, rests on the mercury in the lower reservoir and partly fills the tube above it, the exact level being regulated by means of the three-way cock. Owing to the difference of diameter of the reservoir and of the index tube small differences of level in the former are represented by considerable movements of the meniscus in the latter, and the instrument, when calibrated, is capable of indicating variations of pressure corresponding to $\frac{1}{200}$ millimeter of mercury. The Author suggests a number of practical uses to which this apparatus may be put.

G. J. B.

Experiments on Radiation at Low Temperatures.

By Raoul Pictet.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxix. p. 1202, 1894.)

The Author has conducted a series of experiments on the rate of heating in the case of a body cooled to $-170°$ C., the temperature of the surrounding atmosphere being $+11°$ C.

Refrigerators cooled by a mixture of sulphur dioxide and carbon dioxide, or by liquid nitrous oxide, were employed, and the

thermal capacity of the refrigerator was taken into account in each case.

Five series of experiments were made. In the first the surface of the refrigerator was bare, in the second it was covered with a layer of cotton-waste just sufficient to prevent the formation of hoar-frost upon the metal, and in the third, fourth and fifth series the protecting layers were 10 centimetres, 25 centimetres and 50 centimetres thick respectively.

The results are expressed in graphic form. Between − 170 and − 100 the curves of the rise of temperature follow very nearly the same course, showing that against such intense cold even a thick layer of cotton affords but little protection. At about − 70 there is an almost sudden change in the direction of all the curves, the phenomenon being most marked in the case of the fifth series, but it is only between − 20° C. and + 10° C. that the effect of the protective coverings becomes proportional to their thickness.

The Author considers that bad conductors of heat are capable of absorbing with tolerable completeness the radiations from bodies at temperatures between − 60° C. and + 11° C., but that they are transparent to calorific vibrations emitted when the temperature is below − 60° C.

Other substances, such as silk, wool, sawdust, cork, charcoal-powder, and peat, gave similar results, and in general bad conductors of heat appear to be diathermanous for temperatures between − 100° and − 170° C.

G. J. B.

Experiments on Bottles for holding Carbonic Acid.

By M. Rudeloff.

(Mittheilungen aus den k. technischen Versuchsanstalten zu Berlin, 1894, p. 206.)

Between March and May, 1894, the Aktien-Gesellschaft für Kohlensäure Industrie zu Berlin had sent three pairs of bottles to be tested by internal pressure and by direct tension. The first pair (I*a* and I*b*) were made first as open tubes, and then completely welded at one end, while the other end was narrowed until only a small opening was left. The second pair (II*a* and II*b*), of German manufacture, and the third pair (III*a* and III*b*), of English manufacture, were made from steel blocks drawn several times on a mandril through dies till the required length was obtained, when the open end was reduced until only a small opening was left.

The results of the two methods of test agreed fairly well for the pairs II and III, but for pair I there was a considerable discrepancy. This led to the supposition that the bottles I*a* and I*b* were either made from different kinds of material, or had been subjected to different treatment whereby the properties of the

material were altered in different degrees. It seemed desirable, therefore, to institute more complete experiments to decide whether the bottles of the same pair (1) were made of the same material; (2) had been subjected to the same treatment, so that it would be allowable, knowing the tenacity of the material, to predict its resistance to internal pressure. (3) By comparison between the different results it was to be determined how far (*a*) the tenacity of the material, as given by a straight test piece, is preserved in the manufactured bottle; (*b*) the mode of manufacture influences the strength.

The fracture of III*a* began near one end, continued longitudinally for some distance, and then suddenly assumed a transverse direction, making almost a complete transverse fracture. Since no faults were visible in the material in the neighbourhood of the fracture, it appeared probable that it might be of different hardness, offering greater resistance to tearing in a longitudinal direction. To investigate this (4) a comparative test of the materials on each side of the fracture was made. The methods of cutting the test specimens from the bottles and of conducting the experiments are described at length.

The bottles of both pairs II and III appeared to be made out of similar materials, while those of pair I appeared to be of quite different material. It is impossible, therefore, from a tensile test of the material of one bottle to predict the resistance to internal pressure of another bottle of the same batch.

In testing II*a*, the stress produced was 96·5 per cent. of the observed tensile strength of the material, while in the other bottles it only reached 74 per cent. In discussing these figures it is to be remembered that the tension specimens have to be cut from the bottle after it has been burst, and also that the test specimen has to be straightened.

The top and bottom ends of both pairs I and II were of similar material, while the top end of pair II seemed to be of stronger material than the bottom.

The peculiar form of fracture of III*a* is discussed at some length.

The Paper is accompanied by numerous Tables and two reproductions of photographs showing the bottles after fracture.

A. S.

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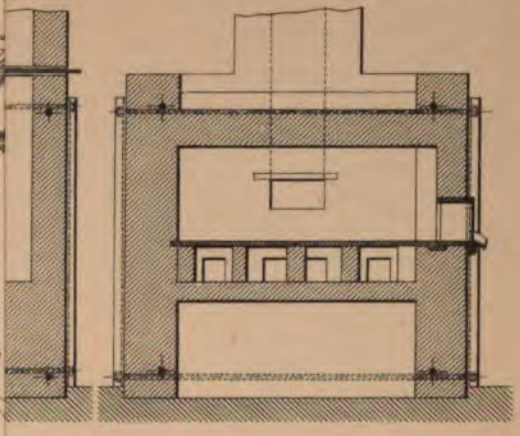
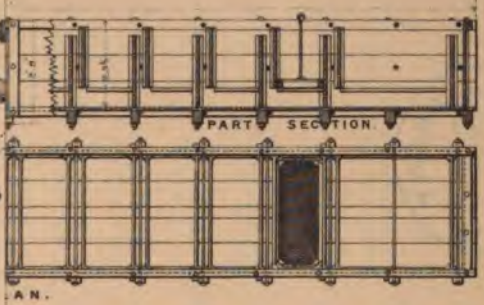
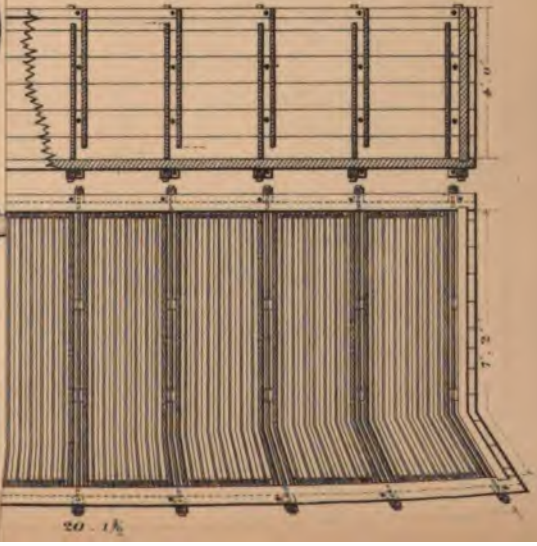
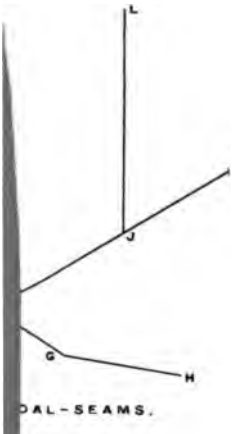


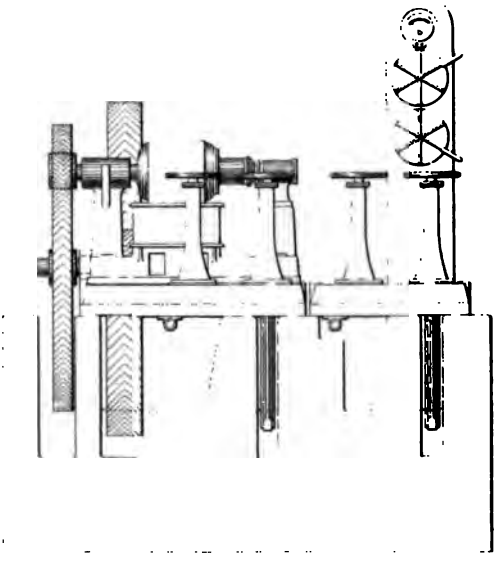




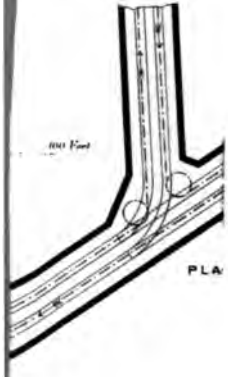
THE ASTOR LIBRARY NY



OAL-SEAMS.



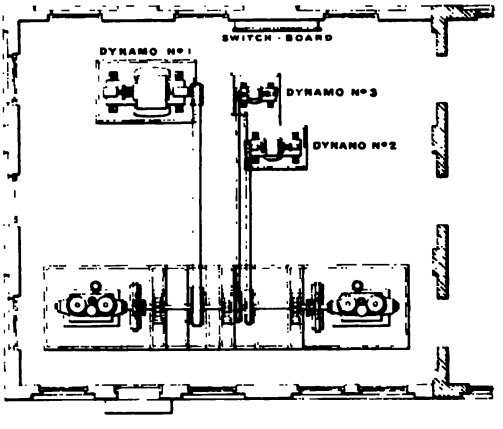
END VIEW.



PLA

Scale for
Scale for

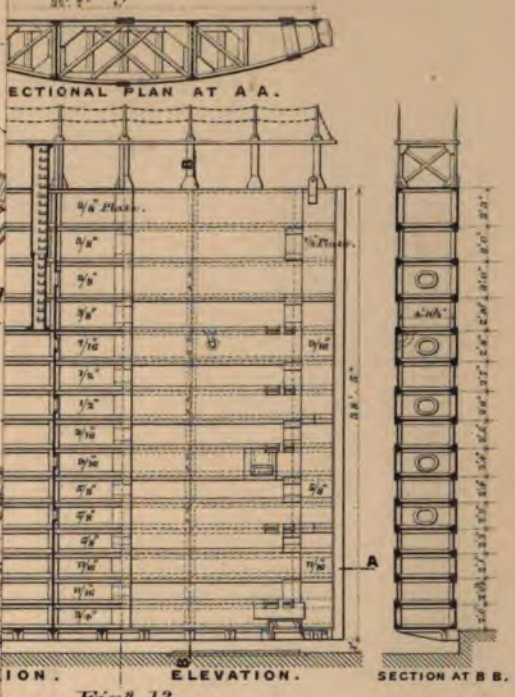
Fig: 2.



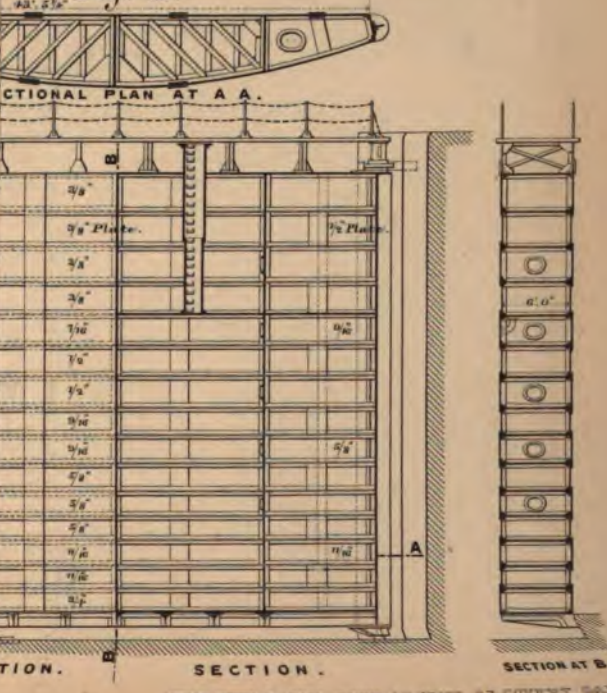
DYNAMO-AND ENGINE-HOUSE.

PLATE 3.

Figs 12.



Figs 13.



THOS KELL & SON, LITH. 440 KING ST COVENT GARDEN

Fig: 30.

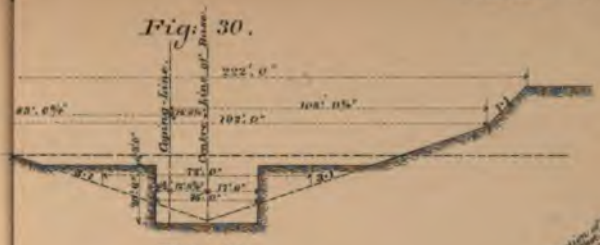
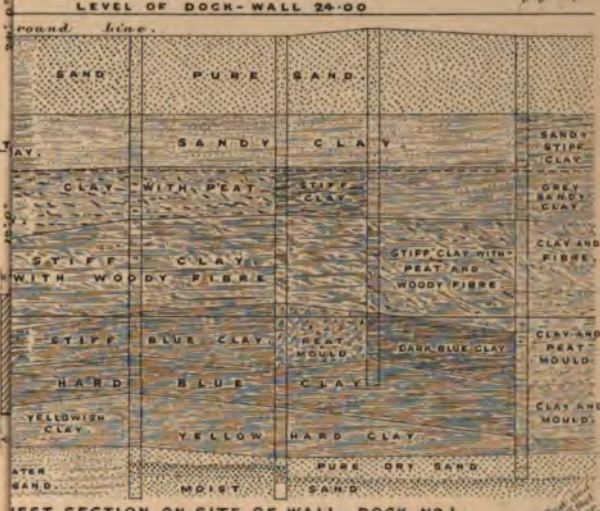
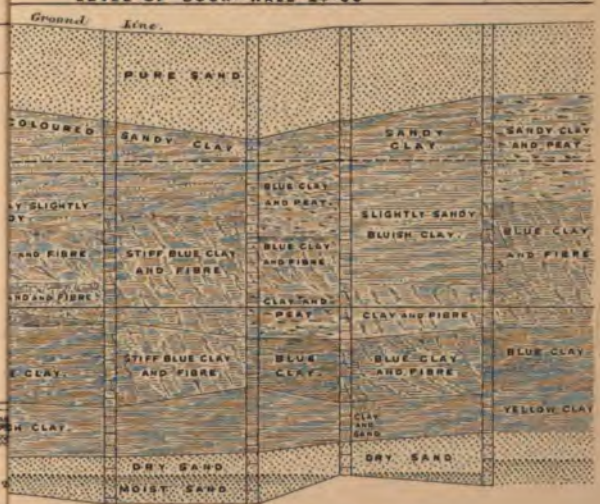


Fig: 28.



WEST SECTION ON SITE OF WALL, DOCK Nº 1.

Fig: 29.



EAST SECTION ON SITE OF WALL, DOCK Nº 1.

THOS KELL & SON, LITH. 40 KING ST COVENT GARDEN.

Halton View
CUERDLEY
Moss Bank
To Manchester
To Manchester
From Liverpool
DITTON
EASTERN OUTFALL
Widnes Marsh
WESTERN OUTFALL
Scale 3 Inches to 1 Mile
0
1/2
1 Mile
OUTFALL
SEWER
DRAINED